TRANSACTIONS

of the

American Society for Steel Treating

Vol. VII May, 1925 No. 5

SPRING SECTIONAL MEETING

PRACTICALLY all of the details of arrangements for the program for the Spring Sectional Meeting being held in Schenectady May 28, 29 and 30 have been made and indications are that this meeting will be one of the most successful and widely attended of all the sectional meetings which have been held by the Society. The Meetings and Papers Committee has arranged a very comprehensive program and the Plant Visitation Committee has made arrangements for some very interesting plant visits.

The new Hotel Van Curler will be headquarters for this meeting. Reservations for accomodations should be made directly with the hotel manager.

The tentative program is as follows:

THURSDAY, MAY 28

Registration—9:30 to 10:00 A. M., at Hotel Van Curler. Miss Dorothy Jane Quinn and Miss Esther Gillfillan, registrars.

Technical Session—10:00—12:00 M., at Hotel Van Curler. V. O. Homerberg, chairman.

Some New Developments in Stainless Steel. P. A. E. Armstrong, vice-president, Ludlum Steel Co.

The Relation of Crystal Orientation to Magnetic Properties of Silicon Steel. W. E. Ruder, metallurgist, research laboratories, General Electric Co.

Case Carburizing. B. F. Shepherd, metallurgist, Ingersoll-Rand Co.

Leave by auto for Watervliet for lunch and inspection of Ludlum Steel Co.'s plant.

Banquet—6:30 P. M., at Hotel Van Curler.

Address of Welcome—William Dalton, president of the Schenectady Chamber of Commerce.

Response—W. S. Bidle, president, A. S. S. T.

Address—Dr. W. R. Whitney, director, research laboratory, General Electric Co.

Address—R. B. McColl, manager, American Locomotive Works.

Paper—*Results of Examination of Metals with X-Rays.* Colonel T. C. Dickson, commanding officer, Watertown Arsenal.

Paper—*Manufacture of Guns by the Cold Working Process.* Dr. F. C. Langenberg, director of laboratories, Watertown Arsenal.

FRIDAY, MAY 29

Meet at Hotel Van Curler at 9:00 A. M.

Inspection of plant of American Locomotive Works until 11:30 A. M. Those who do not desire to visit American Locomotive Works may begin inspection of the plant of the General Electric Co. Both groups will meet at the General Electric Co. for lunch at 1:30 P. M.

Address of welcome—C. C. Eveleth, manager, General Electric Co.

Technical Session—4:00 P. M. in the assembly room of the General Electric Co.'s research laboratory. W. J. Priestly, chairman.

The High Points in the Manufacture and Working of Open Hearth Steel. L. F. Johnson, United Alloy Steel Co.

Second technical paper to be announced later.

6:00 P. M. Informal Dinner—Dining room, Hotel Van Curler.

Technical Session—7:30 P. M. at Hotel Van Curler. H. C. Knerr, chairman.

On the Nature of Austenite and Martensite. E. C. Bain, metallurgist, Union Carbide & Carbon Co.

Manufacture and Heat Treatment of Large Forgings. A. O. Schaefer, Midvale Co.

Determination of Heat Treatment Costs and Furnace Efficiencies. C. L. Ipsen, industrial heating department, General Electric Co.

SATURDAY, MAY 30

Leave promptly at 8:30 A. M. for trip to Lake George. Return about 6:00 P. M.

Members of the Schenectady chapter urge that all those who can possibly arrange to take the Lake George trip should by all means do so, beeause this is a very interesting and beautiful trip

Hotel Van Curler (Headquarters)

to take at this time of the year. Arrangements will be made for luncheon on the trip and cars will be provided for all those who do not drive their own. The return trip from Lake George will be made in time for the night trains to Boston, New York or the West.

It has been requested by the Schenectady Committee that all members who are planning to bring their families with them on this trip, will please communicate with Gerald Brophy, General Electric Company, Research Laboratory, Schenectady, so that the necessary arrangements may be made for the entertainment of the ladies during technical sessions and plant visits. It is urged that the ladies attend this sectional meeting.

REPORT OF SUB-COMMITTEE ON TOOL STEEL

IN the September, 1923, issue of TRANSACTIONS there appeared reports covering Recommended Practice for Heat Treatment of 18 per cent Tungsten High Speed Steel and Recommended Practice for Heat Treatment of Plain Carbon Tool Steel. These two recommended practices have recently been revised by the sub-committee on tool steel incorporating suggestions received from the membership of the A. S. S. T.

These two reports have been adopted by the Recommended Practice Committee and the Board of Directors of the Society and are now standard recommended practices of the Society. Data sheets covering the revisions on these two recommended practices will be issued to the membership in June.

The membership of the sub-committee on tool steel is composed of W. J. Merten, chairman; Messrs. W. H. Phillips, C. I. Neidringhaus, C. M. Johnson, J. P. Gill, J. Trautman, Jr., and DuRay Smith.

This committee has completed part of its program for 1925. The report which follows is the committee's report on the Recommended Practice for the Heat Treatment of Taps and Milling Cutters. This is a tentative recommended practice, and will remain so until it is adopted by the Recommended Practice Committee and the Board of Directors of the Society.

Recommended Practice for the Heat Treatment of Plain Carbon Steel, 18 per cent Tungsten High Speed Steel, and 1.50 to 2.00 per cent Tungsten Tool Steel Taps and Milling Cutters.

GENERAL

THIS recommended practice covers the process to be followed in the heat treatment of taps and milling cutters made from plain carbon tool steel, 18 per cent tungsten high speed tool steel, and 1.50 to 2.00 per cent tungsten tool steel, and must not be applied to taps and milling cutters having a chemical composition other than given on the opposite page:

ANNEALING OF STEEL AFTER FORGING AND BEFORE MACHINING

Operations—Heating and Cooling

Heating—Place steel in furnace on charcoal covered bottom (except high speed steel) and heat slowly and uniformly to tempera-

ture given in Table I and hold at this temperature for sufficient time to obtain complete penetration of heat and complete refinement of grain. It is recommended that the steel, especially the

Approximate Chemical Composition

	Plain Carbon Tool Steel	18 Per Cent Tungsten High Speed Steel	1.50 to 2.00 Per Cent Tungsten Tool Steel
	Per Cent	Per Cent	Per Cent
Carbon	1.00 to 1.30	0.65 to 0.75	1.00 to 1.30
Tungsten	.....	17.50 to 18.50	1.50 to 2.00
Chromium	.....	3.25 to 4.25	0.50 (optional)
Vanadium	.....	0.75 to 1.25	0.25 (optional)
Manganese	0.35 max.	0.35 max.	0.35 max.
Phosphorus	0.030 max.	0.030 max.	0.030 max.
Sulphur	0.030 max.	0.030 max.	0.030 max.
Silicon	0.30 max.	0.35 max.	0.35 max.

high speed steel, be heated in a closed pipe or box containing some carbonaceous material.

Cooling—Cool in furnace, infusorial earth, mica, lime, or any medium that will permit of uniform, slow cooling and prevent excessive oxidation.

Table I
Annealing After Forging and Before Machining

		Heating			
Type of Steel	Method	Temp. Degrees Fahr.	Time of Heating to Uniform Temp.	Time of Holding at Temp. in Hrs.	Cool in
Plain Carbon	Pack anneal or on charcoal bottom	1450	1 hr. per in. of dia. or thickness*	½	Furnace**
18 Per Cent Tungsten High Speed	Non-oxidizing atmosphere	1600 to 1650	1 hr. per in. of dia. or thickness.	½	Furnace
1.50 to 2.00 Per Cent Tungsten	Pack anneal or on charcoal bottom	1475	1 hr. per in. of dia. or thickness	½	Furnace

*When pack annealing, consider the container and contents as one unit.
**If lead bath or salt bath is used for heating, cool in lime, mica, or infusorial earth.

Annealing for Relieving Machining Strains

Operations—Heating and Cooling

Heating—Place taps and milling cutters in box containing some carbonaceous material (except in case of high speed steel). Place

in furnace and heat to temperature given in Table II.

Cooling —Cool in furnace.

Table II
Annealing for Relieving Machining Strains

Type of Steel	Heating: Temp.	Heating: Time of Heating to Uniform Temp.	Time of Holding at Temp. in Hrs.	Cool in
Plain Carbon	1400	1 hr. per in. of dia. or thickness	¼	Furnace
18 Per Cent Tungsten High Speed	1500	1 hr. per in. of dia. or thickness	¼	Furnace
1.50 to 2.00 Per Cent Tungsten	1450	1 hr. per in. of dia. or thickness	¼	Furnace

Heat Treating of Taps and Milling Cutters

Operations—Heating for Quenching; Quenching; Tempering

Heating for Quenching—Heat taps or milling cutters uniformly to temperature given in Table III and hold for complete penetration of heat.

Quenching—Quench from this temperature in air, water, or oil as directed in Table III, but do not cool below the temperature of boiling water, 212 degrees Fahr.

Tempering—After quenching, reheat immediately in oil, salt, or furnace for the time and temperature specified in Table IV.

Table III
Heating and Quenching of Taps and Milling Cutters

Type of Steel	Preheating: Medium	Preheating: Temp. Degrees Fahr.	Heating For Quenching: Heating Medium or Type of Furnace	Heating For Quenching: Temp. Degrees Fahr.	Heating For Quenching: Time	Quenching: Medium	Quenching: Temp. Degrees Fahr.
Plain Carbon..	.....	.....	See Footnote 1	1425 to 1450	1 hr. per in. of dia. or thickness	Water or Brine	Water 70
18 Per Cent Tungsten High Speed.	Open Furnace	1500 to 1550	Open Furnace	2250 to 2300*	See Footnote 2	Oil	70
1.50 to 2.00 Per Cent Tungsten ...	.....	.....	.....	1450 to 1475	1 hr. per in. of dia. or thickness	Water or Brine	Water 70

*A temperature as high as 2350 degrees Fahr. may be used, providing the furnace design is correct and the atmosphere is suitable.

[1]If a lead bath is used for heating, a higher temperature and shorter time should be used. When heating the steel in an open furnace, either an indirect fired furnace (muffle) should be used or a smoky flame should be maintained.

[2]Hold shortest time possible to thoroughly heat through.

Table IV

Tempering of Taps and Milling Cutters

Type of Steel	Results Desired	Tempering Medium	Tempering Temp. Degrees Fahr.	Time
Plain Carbon	See footnote 1	Oil	325 to 500	½ to 1 hour
18 Per Cent Tungsten High Speed.	See footnote 2	Furnace	1100 to 1200	30 minutes
1.50 to 2.00 Per Cent Tungsten...	See footnote 1	Oil	325 to 500	½ to 1 hour

[1]Depending on degree of hardness or toughness desired.
[2]Development of secondary hardness and toughness.

Notes About the Process

In the above practice it it assumed that the tap shanks are below the hardening temperature and are not fully hardened. If the shanks have been fully hardened they must be tempered in order to toughen, especially the smaller sizes.

HONORARY MEMBER OF THE SOCIETY DIES

ELWOOD Haynes, Honorary Member of the American Society for Steel Treating and widely known scientist and metallurgist, died on April 13 at his home in Kokomo, Indiana, at the age of 68 years. Mr. Haynes was born in Portland, Indiana in 1857 and was graduated from the Worcester Polytechnic Institute in 1881, during which time he had specialized in physics, chemistry and the development of tungsten steel. In 1887 Mr. Haynes began his work on the automobile and a few years later began actual construction on the first automobile. He was particularly well known for his development work on "stellite," which is a high speed alloy cutting material widely used in the industry. He has done extensive work on the alloying of various elements in the production of tools for cutting processes. In 1921, Mr. Haynes was elected an honorary member of the Society in recognition of his valuable research work in metallurgy.

UNAUDITED PROFIT & LOSS STATEMENT
AMERICAN SOCIETY FOR STEEL TREATING

From January 1 to March 31, 1925

INCOME		
Dues (Gross)	$11,035.10	
Transactions Advertising	6,070.10	
Transactions Sales	624.75	
Bindery Account	331.50	
Discounts Received	78.16	
Interest	18.88	
Data Sheets	599.95	
Miscellaneous Receipts	357.55	$19,115.99
EXPENSES		
Discounts Allowed	$ 63.85	
Bindery Account	63.85	
Reprints	206.20	
Data Sheets	945.07	
Library	78.53	
Transactions Advertising Expense	550.38	
Miscellaneous Expenses	95.61	
Transactions	5,816.27	
Secretary's Office	2,818.90	
President's Office	370.26	
Treasurer's Office	441.95	
Director's Expenses	426.15	
National Committees	1,328.06	
Sectional Meeting—Cincinnati	361.77	
Sectional Meeting—Schenectady	40.52	
Local Chapters	4,297.71	
1924 Convention Expenses	25.00	17,930.08
Excess of Income over Expense		$ 1,185.91

BALANCE SHEET

ASSETS		
Commercial Account Cleveland Trust Co.	$ 4,502.28	
Savings Account Cleveland Trust Co.	5,109.28	
Savings Account Equity Savings & Loan Co.	21,412.40	
Savings Account Union Trust Co.	1,126.14	
Bond Investments	31,000.00	
U. S. Treasury Certificates	2,165.00	
Accounts Receivable for Advertising	1,854.15	
Accounts Receivable Miscellaneous	1,195.78	
Office Furniture and Fixtures	525.00	
1924 Convention Accounts Receivable	20.00	
1925 Convention Prepaid Expenses	2,309.86	
Accrued Interest	292.92	
Inventory January 1, 1925	2,631.00	$74,143.81
LIABILITIES		
Accounts Payable	$ 1,638.75	
Reserve for Dues Paid in Advance	10,000.00	
Reserve for Doubtful Accounts	1,000.00	
Permanent Convention Reserve	20,000.00	
Advance Receipts 1925 Convention	9,202.50	
H. M. Howe Medal Fund	3,000.00	
Surplus, January 1, 1925	$28,116.65	
Profit from January 1 to March 31, 1925	1,185.91	29,302.56 $74,143.81

SOME PHYSICAL PROPERTIES OF LOW CARBON STEEL

By R. H. Smith

Abstract

The object of the present paper is to tabulate and describe the practical results obtained by the heat treatment of low carbon steel with an accurate control of heating temperature and media of quenching.

The results show that the tensile strength per square inch and other physical properties such as elongation, reduction of area and hardness may be accurately controlled in their relationships to each other, and may be varied over a wide range by suitable quenching.

Practically any physical properties which have heretofore been demonstrated as possible to secure by heat treating and subsequent tempering at a proper temperature may likewise be obtained in a single quench by accurately controlling the cooling medium, its velocity and temperature, and the correct temperature of the steel from which the quench is made.

IN a recent paper[1], the writer pointed out the very great increase in tensile strengths that are possible with low carbon steels effective with increase in temperature of heat treatment and increased speed of quenching. These results are well illustrated in Fig. 3 which has been taken from this paper. It might briefly be said that each point on the curves represents the average of three tests on standard specimens as illustrated in Fig. 1. These specimens were heated in a lead pot, which in turn was heated by an electric resistance furnace, and the quenching was done in a jig as illustrated in Fig 2. For a more detailed description, see the paper above referred to.

While an effort was made to confine this previous discussion to results of general interest, it is the purpose of the present paper to give more concrete and practical applications. In such practical application there is no more important feature shown by the laboratory experiments than the 'reduction of area' curve, as shown in

[1]High Tensile Strengths with Low-Carbon Steel, R. H. Smith, American Society for Testing Materials, June, 1924.

A paper presented before the Cleveland Chapter and Winter Sectional Meeting, Cincinnati, January, 1925. The author, Major R. H. Smith, member A. S. S. T., is vice-president, Lamson and Sessions Co., Falls Rivet Plant, Kent, Ohio.

Fig. 3. It shows clearly the reasons for so many perplexing failures of bolts, rivets, etc. Everyone familiar with such "trouble" jobs knows how frequently it is that conditions are met with which are difficult to explain. Failures of bolts are variously explained as

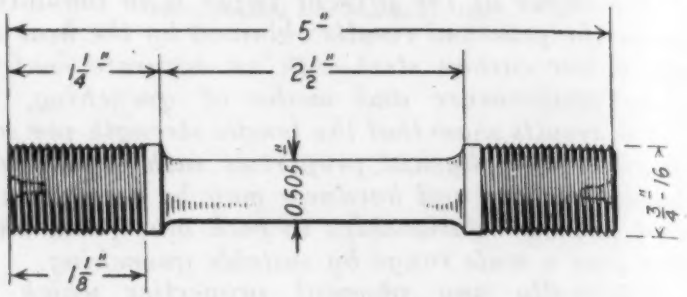


Fig. 1—Sketch of Tensile Test Specimen Used in Conducting this Research Work.

due to "acid brittleness" or "burnt steel" or just plain "crystallized steel." It is doubtful if low carbon steel is ever "burnt" under any condition of practical work, and "crystallized steel" is just another name for miserably poor control of heat treatment.

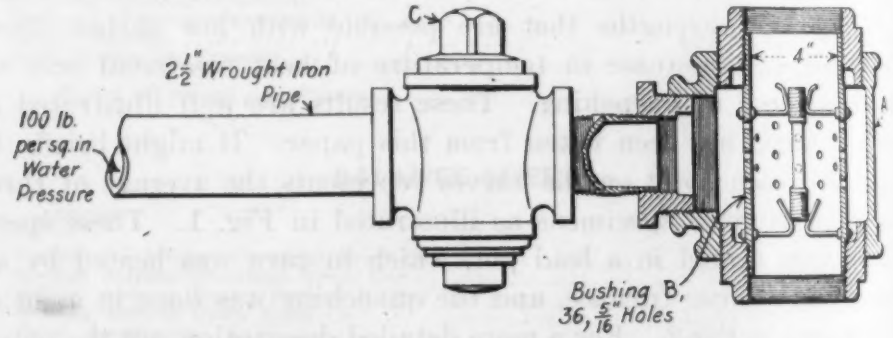


Fig. 2—Diagram Showing Quenching Jig and Fixture for Quenching Test Bars.

As for the excuse "acid brittleness"— this may cover a multitude of sins of the careless or unskilled manufacturer. Langdon and Grossmann[2] have shown conclusively that true "acid brittleness" can enter only to a small degree into the physical properties of bolts when a heat treatment or annealing is the last operation through which they pass. In other words, bolts that are heat treated and not later cleaned in acid for galvanizing are to all intents and purposes immune to "acid brittleness."

It would seem more probable that all three conditions are but

[2]Embrittling Effects of Cleaning and Pickling upon Carbon Steels, Langdon and Grossmann, American Electro-Chemical Society, 1920.

different names for the same thing which is associated with some previous experience of the steel in this critical range. Many writers, notably Hillman[3], have pointed out the extreme danger of annealing low carbon steel in this critical temperature range after

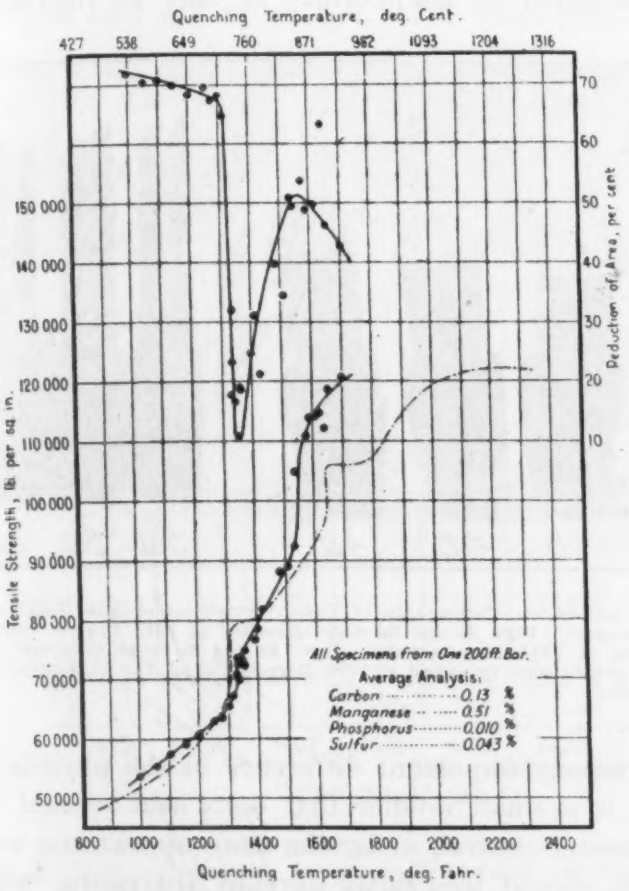

Quenching Temperature, deg. Cent.
427 538 649 760 871 982 1093 1204 1316
Tensile Strength, lb. per sq. in.
150 000 140 000 130 000 120 000 110 000 100 000 90 000 80 000 70 000 60 000 50 000
Reduction of Area, per cent
70 60 50 40 30 20 10
All Specimens from One 200 ft. Bar.
Average Analysis:
Carbon ..... 0.13 %
Manganese ..... 0.51 %
Phosphorus ..... 0.010 %
Sulfur ..... 0.043 %
800 1000 1200 1400 1600 1800 2000 2200 2400
Quenching Temperature, deg. Fahr.

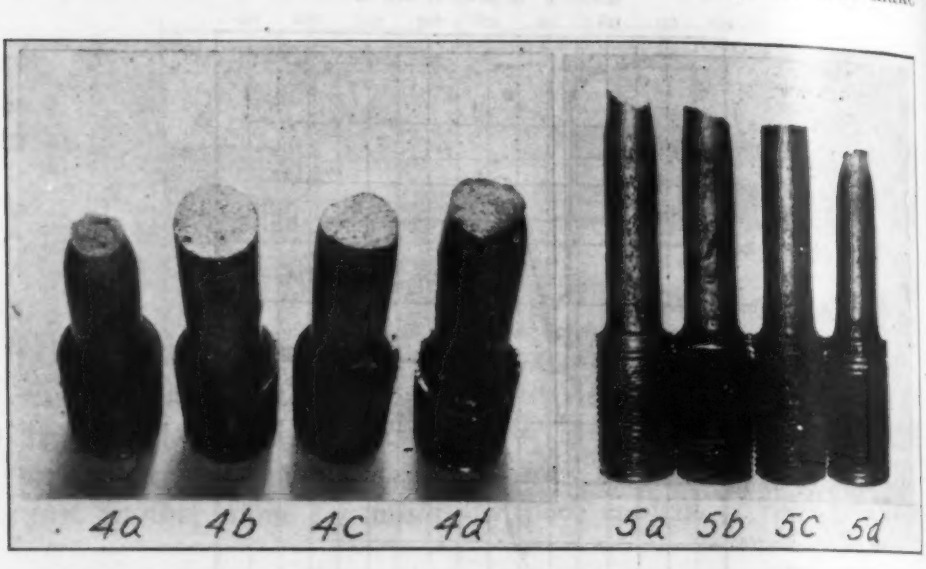
Fig. 3—Curves Showing the Tensile Strength and Reduction of Area of an 0.13 Per Cent Carbon Steel Quenched in the Fixture Shown in Fig. 2.

it has been subjected to cold working strains. Our own curve shows an equally dangerous condition from heat treating hot-worked or carefully normalized steel in this temperature range.

Figs. 4 and 5 show four typical fractures of specimens at temperatures 1315 to 1700 degrees Fahr. (712 to 926 degrees Cent.) The excellent shape and the great reduction of area, Figs. 4a and 5d at 1315 degrees Fahr. (712 degrees Cent.) will be noted. By raising the quenching temperature just 20 degrees

[3]Cold Headed Bolts—Their Metallography and Heat Treatment, V. E. Hillman, TRANSACTIONS of American Society for Steel Treating, Vol. II, 1922, page 369.

to 1335 degrees Fahr. (724 degrees Cent.), practically all reduction of area is eliminated (Figs. 4b and 5c) and the specimen becomes brittle, and coarsely crystalline in fracture, matching exactly the so-called "burnt," "acid brittle" and "crystalline" failures. When a variation in temperature of only 20 degrees will make



Figs. 4a-4d and 5a-5d—Photographs of Typical Fractures of Steel Specimens Quenched at Different Temperatures. Figs. 4a and 5d were Quenched at 1315 Degrees Fahr. Figs. 4b and 5c were Quenched at 1335 Degrees Fahr. Figs. 4c and 5b were Quenched at 1600 Degrees Fahr. Figs. 4d and 5a were Quenched at 1700 Degrees Fahr. The Variations in the Reduction of Areas are Marked.

such an extremely important difference in the physical properties of the bolt, it is small wonder that bolts heat treated without accurate pyrometer control, or by the mere appearance to the eye of suitable heat, should frequently develop distressing failures. The fracture improves again with increase in the temperature until it is excellent (Figs. 4c and 5b) after heat treating to about 1600 degrees Fahr. (871 degrees Cent.). It is worth while to note that we were not successful in developing this extremely brittle range in steel that had previously received this drastic quench from a temperature above the upper critical. In other words, as frequently happens, a rivet made by the cold upsetting process is driven hot; if such rivet is heat treated at 1600 to 1700 degrees Fahr. (871-926 degrees Cent.) with this rapid quenching, no crystalline or bad fracture of the driven rivet can occur, no matter how unskillful the man heating the rivets may be. On the other hand, when such rivets are driven, as is customary, without such pre-

vious heat treatment, trouble in a certain proportion (depending on the skill of the heater and previous history of the steel) is inevitable.

Fig. 9 is a photograph of a rivet head from a 1¼-inch rivet which was made cold and driven hot. This rivet head snapped off

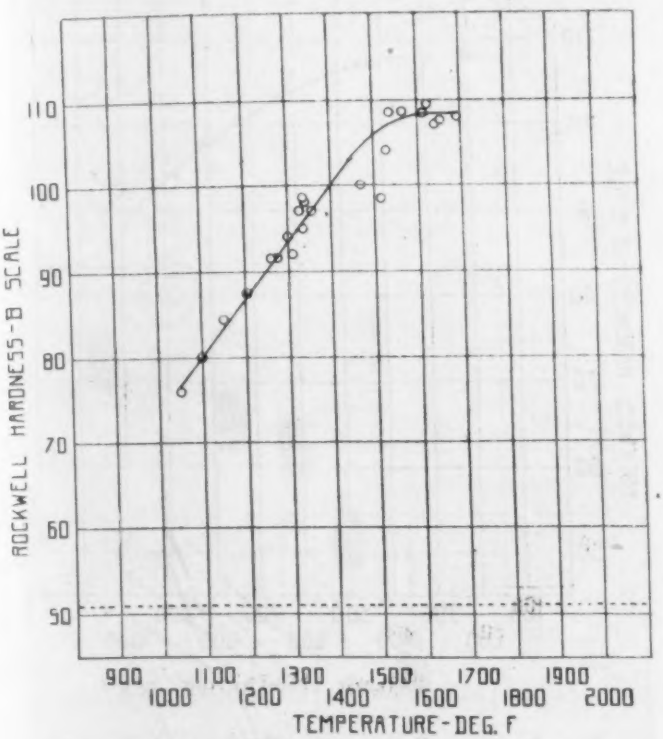


Fig. 6—Curve Showing the Manner in Which the Hardness of the Specimen Increases with Increase in Temperature and Becomes a Maximum at or Near the Upper Critical Point.

and in doing so the riveter lost the sight of one eye. Fig. 10 shows heads of ¾-inch rivets made hot and driven hot, but which developed the same typical structure and caused a heavy financial loss. Both of these failures could have been rendered impossible by the described heat treatment.

The hardness seems to go up uniformly with the temperature to a maximum at or near the upper critical as shown in Fig. 6. Specimens quenched at 1700 degrees and tempered at various temperatures show a hardness declining with the temperature to a minimum at about 1250 degrees Fahr. (676 degrees Cent.) as shown by the curve in Fig. 7.

Quenched at 1700 degrees Fahr. (926 degrees Cent.) with a tensile strength of 120,000 pounds per square inch and a reduction of area around 40 per cent, specimens tempered at the successive temperatures for one hour show a uniform increase in the reduc-

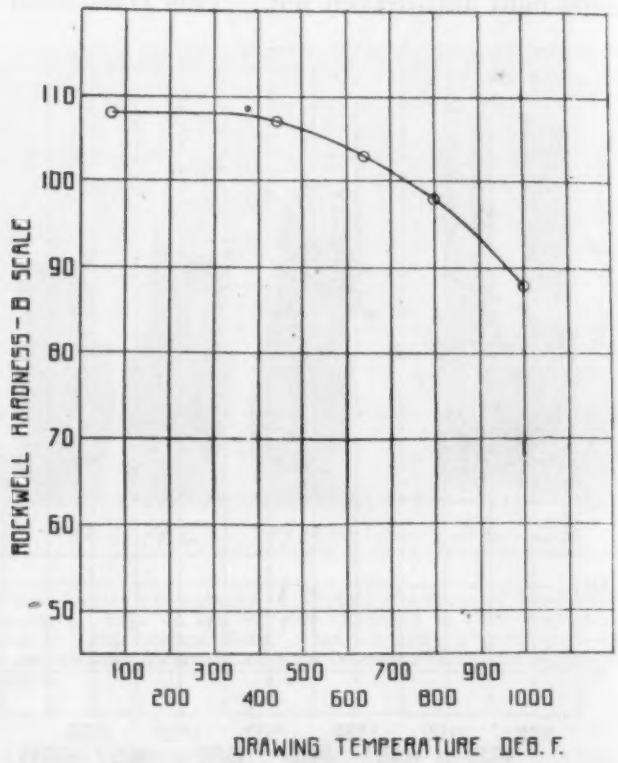


Fig. 7—Curve Showing the Hardness of Specimens Quenched at 1700 Degrees Fahr. to Decline with Tempering Temperature to a Minimum at or about 1250 Degrees Fahr.

tion of area and decrease in tensile strength as shown in Fig. 8. From the curve in this figure it is seen how readily any combination of strength and ductility (of which reduction of area is a measure) within the range of possibility of the steel may be obtained. Many million bolts and rivets have been heat treated to parallel the physical properties indicated by these curves. A typical specification follows:

Tensile Strength—80,000 pounds per square inch, minimum
Elongation in 1 inch—15 per cent, minimum
Brinell Hardness—155 maximum.

These three qualities are in a measure contradictory in low carbon steel (in this case 0.12 per cent and under.) Omit any one

of them and the specification is easier to fulfill. Bolts to this specification are readily made in tonnage production and with the ordinary unskilled furnace attendants.

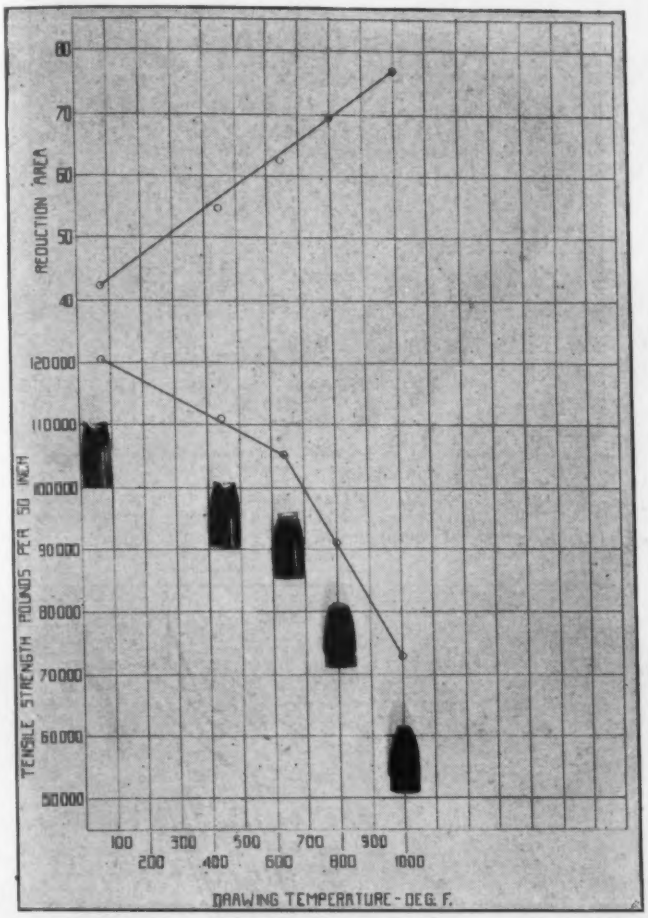


Fig. 8—Curve Showing the Tensile Strength and Reduction of Area of an 0.12 Per Cent Carbon Steel when Quenched at 1700 Degrees Fahr. and Subjected to Successive Tempering Temperatures up to 1000 Degrees Fahr. A Portion of the Tensile Test Bars Showing the Various Amounts of Reduction of Area are Superimposed Upon this Chart.

It has not been so readily apparent that these self same results can be obtained with extreme accuracy with a single quench and although we have no carefully worked out curve of tests to show it, we do have considerable evidence to prove it to be true. H. J. French and O. Z. Klopsch[4] have shown how the rate of cooling affects the structure of steel of higher carbon content. Using

[4]Quenching Diagrams for Carbon Steels in Relation to Some Quenching Media for Heat Treating, TRANSACTIONS American Society for Steel Treating, Vol. VI, 1924, page 251.

as a basis the data shown in their paper, we now readily duplicate, so far as practical results are concerned, with a single quench any of the combinations of quench and temper possible with the two

Fig. 9—Photograph of a Rivet Head from a 1¼-Inch Rivet. This Rivet had been Made Cold and Driven Hot. This Rivet Head Snapped Off After Being Driven.

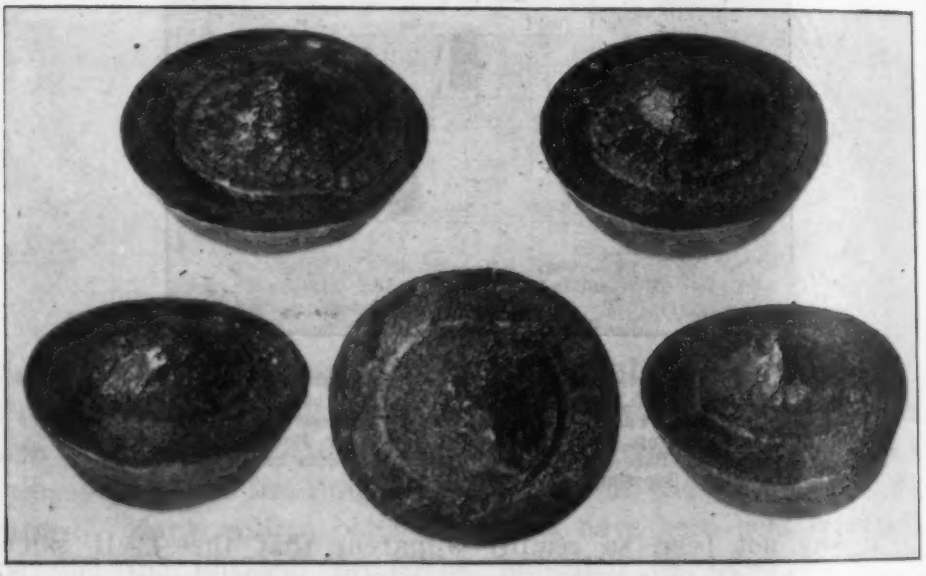


Fig. 10—Shows the Heads of ¾-Inch Rivets Made Hot and Driven Hot but Which Developed a Coarse-Grained Condition. Heavy Financial Loss was Experienced in the Case of These Particular Rivets. The Rivets had Not Been Given Previous Heat Treatment.

treatments. This method is far past its experimental stage and is both easier to control and on the whole more uniform in practical result than the longer and more expensive method.

Fig. 11—This Photograph Shows the Quenching Device Which is Used in the Commercial Production of Rivets and Bolts. Tensile Strengths as High as 160,000 Pounds Per Square Inch on Low Carbon Steels (0.09-0.15 Per Cent Carbon) Can Be Obtained by Means of this Equipment. (Photograph courtesy Iron Trade Review.)

In the paper before the A. S. T. M., it was remarked that the temperature of the quenching medium apparently affected the results very little. This is not strictly true, and we do get a wide variation between iced-brine, for example, and hot water. In the

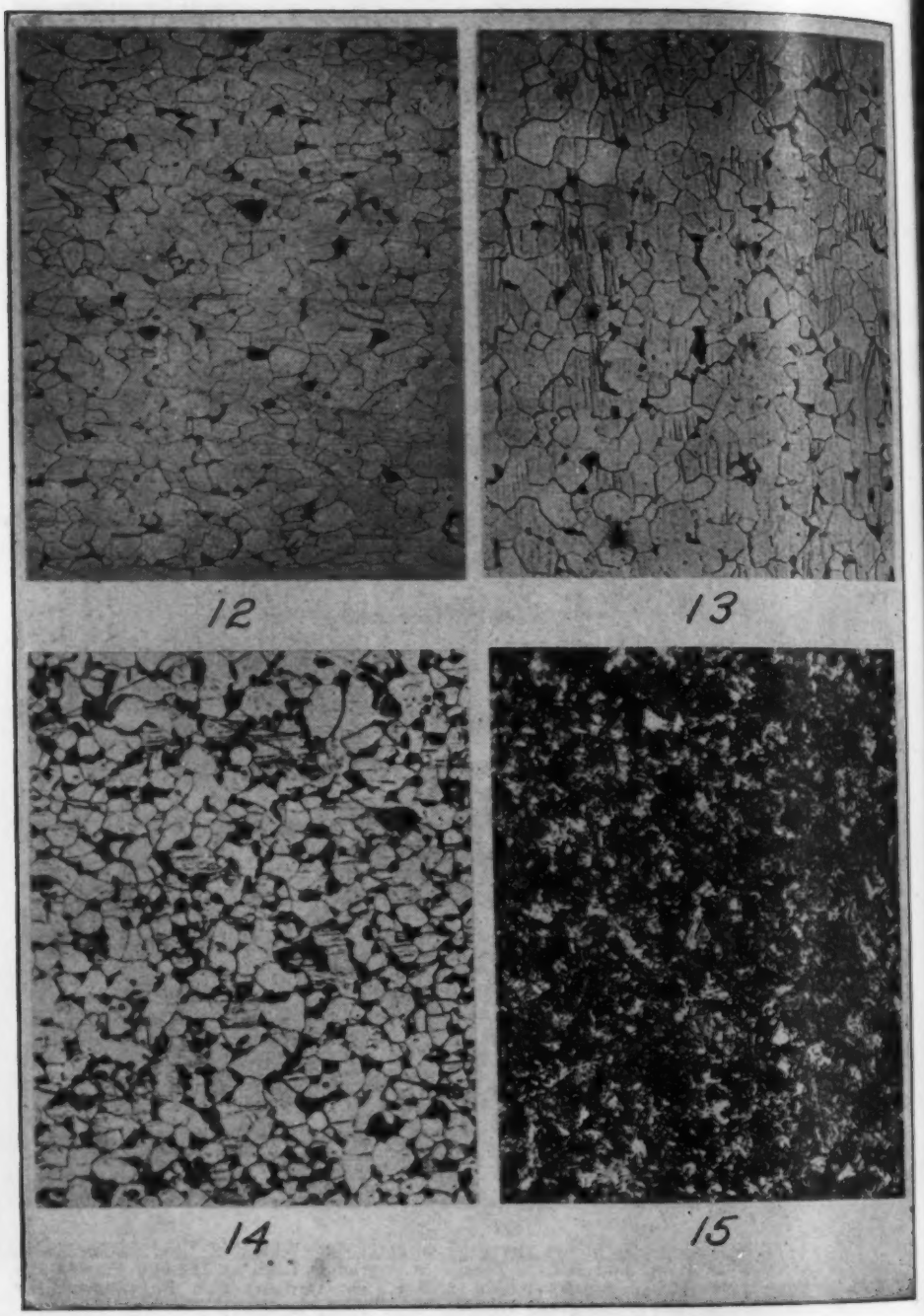


Fig. 12—Microstructure of Normalized 0.09 Per Cent Carbon Steel Having an Ultimate Tensile Strength of 47,800 Pounds Per Square Inch. Fig. 13—Photomicrograph of an 0.09 Per Cent Carbon Steel Quenched from 1305 Degrees Fahr., Having an Ultimate Tensile Strength of 71,860 Pounds Per Square Inch. Fig. 14—Photomicrograph of an 0.09 Per Cent Carbon Steel Quenched from 1470 Degrees Fahr., Having an Ultimate Tensile Strength of 83,000 Pounds Per Square Inch. Fig. 15—Photomicrograph of an 0.09 Per Cent Carbon Steel Quenched from 1630 Degrees Fahr., Having an Ultimate Tensile Strength of 97,670 Pounds Per Square Inch. Magnification 100x.

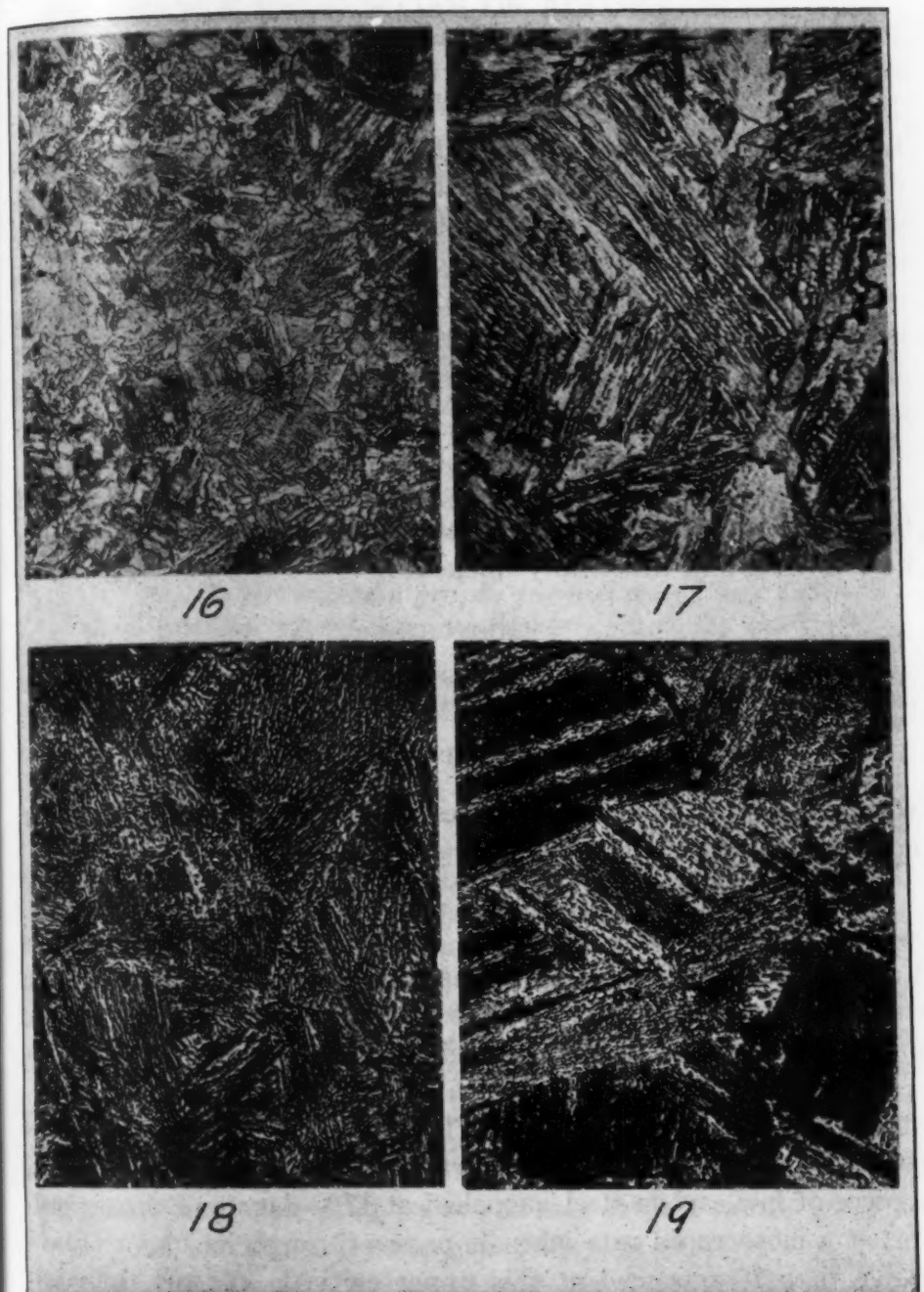


Fig. 16—Photomicrograph of an 0.09 Per Cent Carbon Steel Quenched from 1890 Degrees Fahr., Having an Ultimate Tensile Strength of 112,000 Pounds Per Square Inch. Magnification 100x. Fig. 17—Photomicrograph of an 0.09 Per Cent Carbon Steel Quenched from 1890 Degrees Fahr., Having an Ultimate Tensile Strength of 112,000 Pounds Per Square Inch. Fig. 18—Photomicrograph of an 0.09 Per Cent Carbon Steel Quenched from 2100 Degrees Fahr., Having an Ultimate Tensile Strength of 122,000 Pounds Per Square Inch. Fig. 19—Photomicrograph of an 0.13 Per Cent Carbon Steel Quenched from 1695 Degrees Fahr., Having an Ultimate Tensile Strength of 122,000 Pounds Per Square Inch. Magnification of Figs. 17, 18 and 19, 500x.

tests for curve Fig. 1, we could measure no difference in quenching result between 57 and 63 degrees Fahr. for the fresh cooling water. In the practical fixture for heat treating bolts or rivets, in quantity, (Fig. 11) we use soluble oil at a temperature of 180 to 200 degrees Fahr., fresh water, or other media according to the finish wanted. With the valve wide open, giving full play to the volume of supply, we have no difficulty in getting more than 100,000 pounds per square inch tensile strength. By partially closing the supply valve, suiting the volume to the structure desired, we can produce any result, i. e., we can obtain a continually falling strength and an increase in the reduction of area. This process can be continued until the best of soft rivet conditions are obtained.

The photomicrographs shown in Figs. 12 to 19 show some of the structures which are obtainable with low carbon steels when heat treated and drastically quenched.

Quenching

The theoretically fastest possible cooling rate for steel in a "perfect" medium (neglecting effect of ends) is

$$T = D^2$$

where D is the diameter in inches and T the time in seconds, or more accurately

$$S \times D^2 = C$$

where S is the cooling velocity at 1325 degrees Fahr. (720 degrees Cent.); D is the diameter in inches, and C is the constant to take care of all other variables, such as quenching solution, temperature of quenching, type of material being quenched, etc.

In practice the greatest possible cooling rate from a temperature T to a final temperature TT is obtained when the steel has cooled at its center about one-fourth of its range. In other words, a piece of low carbon steel quenched at 1700 degrees Fahr., is cooling at a more rapid rate when it passes through its upper critical range than if quenched at this upper critical. To get the maximum rate of cooling as the upper critical is passed it would be necessary to quench from about 2000 degrees Fahr. From these conditions it should ultimately become possible to predict a cooling medium, its velocity, etc., for the production of the correct rate of cooling to produce any required result within the possibilities of the steel itself.

ENDURANCE PROPERTIES OF ALLOYS OF NICKEL AND OF COPPER—PART III*

By D. J. McAdam, Jr.

Abstract

In continuation of the investigation of the effect of cold working described in Parts I and II, this paper describes results of investigation of the effect of several degrees of cold working on the rotating-cantilever endurance properties of nickel. The effects of cold working and annealing on endurance and other physical properties of nickel and some of its alloys are illustrated by graphs. The effect of degree of cold working on endurance properties is also illustrated by graphs. A few results are presented of investigation of the effect of cold working on alternating-torsion endurance properties.

Tensile stress-strain graphs for nickel and two alloys show relation of rotating-cantilever endurance limit to proportional limit, elastic limit and proof stress, also the effect of cold working and annealing on this relationship.

Investigation of the effect of chemical composition on the endurance properties of nickel-copper alloys, discussed in Part II, has been continued. The rotating-cantilever composition graph given in Part II has been supplemented and corrected. An alternating-torsion graph has been drawn showing tentatively the effect of chemical composition on this property.

The stress-cycle graphs here shown give additional evidence that the rotating-cantilever endurance limits of the alloys of nickel and of copper are as definite as the endurance limits for steel.

Introduction

In part I[1] of the series of papers on this subject results were presented of endurance tests on many alloys of nickel and of copper. Endurance limits were estimated and the relationships of endur-

*This paper is published by permission of the Secretary of the Navy.

[1]Parts I and II of this paper were published in the January and February, 1925, issues of Transactions, Vol. VII, pages 54 and 217.

A paper presented before the Boston Convention of the Society, September, 1924. The author, D. J. McAdam, Jr., member A. S. S. T., is metallurgist with the U. S. Naval Engineering Experiment Station, Annapolis, Maryland.

ance limits to tensile, torsional and shearing strength were discussed.

Part II described an investigation of the effect of severe cold working on the endurance properties of nickel and of moderate cold working on the endurance properties of several alloys. Part II also discussed the effect of annealing on the properties of cold-worked nickel.

The conclusion was reached that moderate cold working has little effect if any on the rotating-cantilever endurance-ratio, but that severe cold working lowers the endurance ratio.

By means of the information thus obtained the rotating-cantilever endurance-limits of a number of alloys in the annealed condition were calculated from the endurance limits of the same endurance alloys as rolled or drawn. These endurance limits were utilized in graphs to illustrate the influence of chemical composition on endurance properties.

Since the time Parts I and II were published, investigation of the effect of cold working on endurance properties has been continued. This investigation includes several additional samples of nickel that had been cold-worked with different degrees of severity, also cold-worked monel metal and constantan. The results obtained with cold-worked nickel and its alloys now make it possible to draw graphs representing the effect of the degree of cold working on rotating-cantilever endurance properties. A few results of an investigation of the effect of cold working on alternating-torsion endurance-properties are presented and discussed.

Investigation of the effect of chemical composition on the endurance properties of nickel-copper alloys has been continued. Results obtained with a nickel-copper alloy having about 55 per cent nickel, with a nickel-copper-manganese alloy, and with the above mentioned monel metal and constantan, are now available for use in correcting and supplementing the tentative graph in Fig. 5 of Part II.

Material

The material was received in the form of bars. The International Nickel Company generously co-operated by furnishing material well adapted for the purpose of the investigation. Table I gives the chemical composition of the nickel-copper alloys discussed in Parts I and II and the additional nickel-copper alloys

discussed in the present paper. Instead of trade names each material has been designated by a combination of letters.

Results of Tension Tests

Results of tension tests on the wrought nickel-copper alloys are given in Table II. The material designations are the same as in Table I. Instead of a yield point, Johnson's limit was determined whenever possible. Johnson's limit is the point at which the tangent of the angle between the stress-strain graph and the vertical has become 50 per cent greater than it was at the origin of the graph.

By elastic limit is meant the maximum stress that produces no permanent deformation. The proof stress is the stress that produces a permanent deformation of 0.0002 inches on a 2-inch gage length (0.01 per cent). The speed control of the machine below the proof stress was set to a point that would give a speed of 0.0367 inches per minute with no load on the machine. Above the proof stress the corresponding position of the speed control indicated 0.391 inches per minute.

Results of Static Torsion Tests

Results of static torsion tests are given in Table III. The specimens for these tests had a test diameter of ¾ inches. For calculating the nominal torsional strength the formula used for calculating stresses below the elastic limit was multiplied by 0.75.

Results of Shear Tests

Results of shear tests on cold-worked material and on the same material after annealing at various temperatures, are given in Table IV. For comparison, the tensile strength and the ratio of shearing strength to tensile strength are given in parallel columns. Other results of shear tests are given in Table VI.

The shear tests were made with cylindrical specimens ¼-inch in diameter. Each specimen was tested in double shear, the sheared sections being ½-inch apart. The shearing strength was calculated by dividing the shearing load by the area in both sheared sections.

Annealing Treatment

Details of annealing treatment for each material are given in Table V.

Specimens and Machines

The specimen used in rotating-cantilever tests was described in Part I. The taper of this specimen is so designed that the maximum stress is about ¾-inches out from the fillet and over a length of about 1½-inches the stress does not vary more than about 1½ per cent. A specimen of this type breaks somewhere in the conical surface, never in either fillet.

Table I
Chemical Composition of Alloys
All Values in Per Cent

Material	Material Designation	C	Ni	Cu	Zn	Fe	Mn	Si	P	S
Nickel, Cold-Rolled	A	0.25	98.95	0.12	....	0.50	0.10	0.06	....	0.175
Nickel, Cold-Rolled	CT	0.10	99.07	0.20	....	0.47	0.07	0.07	....	0.018
Nickel, Cold-Drawn	CRB	0.099	98.70	0.23	....	0.74	0.16	0.06	....	0.16
Nickel, Cold-Drawn	CRA	0.118	98.63	0.23	....	0.72	0.22	0.08	....	0.0024
Nickel, Cold-Drawn	CR	0.05	98.80	0.21	....	0.64	0.28	0.01	....	0.015
Nickel, Hot-Rolled	AW	0.10	98.86	0.19	....	0.64	0.21	0.01	....	0.015
Nickel, Hot-Rolled	AWa	0.044	99.07	0.159	....	0.59	0.184	0.008	....	0.025
Nickel, Hot-Rolled	AWb	0.034	98.74	0.17	....	0.82	0.21	0.01	....	0.022
Monel Metal, Cold-Rolled.	BH	0.216	72.91	23.56	....	1.73	1.94	0.075	....	0.007
Monel Metal, Cold-Drawn.	CS	0.21	67.74	28.64	....	1.75	1.62	0.01	0.014	0.019
Monel Metal, Hot-Rolled.	AA	0.16	66.78	29.54	....	2.10	1.44	0.02	0.019	0.039
Monel Metal, Cold-Rolled.	BK	0.26	76.66	21.28	....	1.40	0.258	0.065	0.023	0.0063
Nickel-Copper-Manganese Alloy	C	0.20	67.51	26.23	....	1.39	4.31	0.40	0.024	0.028
Nickel-Copper Alloy	CU	0.016	55.23	44.18	....	0.44	0.36	0.002	0.006	0.009
Constantan, Cold-Rolled..	CV	0.078	44.77	53.71	....	0.66	0.89	....	....	....
Constantan, Hot-Rolled...	CE	0.11	44.68	53.77	....	0.52	1.14	....	....	....
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	0.07	29.08	69.82	....	0.25	...	Sn0.95	....	....
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD	0.07	19.75	74.01	5.17	0.34	0.75	....	....	....
Copper Nickel Alloy, Cold-Rolled	B	0.03	19.23	80.34	none	0.27	0.12	....	....	....

The method of polishing the specimens for the endurance tests discussed below was as described in Part I. The type of finish used was in that designated in Part I as "Finish 13."

The alternating-torsion specimens were as shown in Fig. 9 of Part I and the same designations are used. The rotating-cantilever machines and the alternating-torsion machine of the inertia type,

described in Part I, were used in the endurance tests to be described.

Effect of Cold Working and Annealing on Rotating-Cantilever Endurance Properties

The endurance properties of a sample of severely cold-worked nickel, Material A, were discussed in Part II. The endurance properties of four samples of nickel that had been less severely cold-worked are now to be illustrated and discussed. The first of these samples, material CT, had been cold-worked enough to increase the tensile strength about 60 per cent above that of the same material when fully annealed. The other three samples, materials CRB, CRA and CR had been cold-worked enough to increase their tensile strength about 32 per cent above that of the same material when fully annealed. Although it had been supposed that these three samples were from the same melt, it was found that they differed in composition and in physical properties in the annealed condition. They are, therefore, from different melts.

Stress-cycle endurance graphs for these four samples of nickel, and for a sample each of cold-worked monel metal and constantan, are shown in Figs. 1 to 4 inclusive. These graphs show the endurance properties of the material as received and after annealing at various temperatures. For four of these materials four other sets of graphs, Figs. 5 to 8 inclusive, have been drawn to show how the physical properties are affected by temperature of anneal. From the data in Figs. 5 to 8 other graphs, Figs. 10 and 11 have been drawn to show how physical properties are affected by the degree of cold working.

Stress-cycle Graphs for Material CT

Results of rotating-cantilever endurance tests on cold-rolled nickel, material CT, are represented on a semi-logarithmic scale in Fig. 1. In the upper graph are shown results obtained with the nickel as received and with the same material after annealing at 550 degrees Fahr. To designate these two materials two kinds of marks are used as described in the "legend." As shown in this graph, the endurance properties have not been affected by annealing at 550 degrees Fahr. The slope of the line representing average

Table II
Average Results of Static Tension Tests
Each Value is Average of Two Determinations Except as Indicated

Material	Material Designation	Heat Treatment	Tensile Strength, Lbs. per Sq. In.	Johnson's Limit, Lbs. per Sq. In.	Proof Stress, Lbs. per Sq. In.	Elastic Limit, Lbs. per Sq. In.	Proportional Limit, Lbs., per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent
Nickel, Cold-Rolled	A	xAs Received	**166,200	**108,600	**109,000	**74,600	**71,600	**12.2	**18.8
Nickel, Cold-Rolled	A-5.5	Annealed	165,500	112,000	103,500	71,000	69,000	14.0	21.9
Nickel, Cold-Rolled	A-8.5	Annealed	160,000	111,000	109,000	92,500	64,800	14.0	25.1
Nickel, Cold-Rolled	A-9.5	Annealed	150,300	98,000	96,500	83,000	81,500	17.8	25.8
Nickel, Cold-Rolled	A-10.0	Annealed	151,500	95,500	70,000	31,500	29,000	18.0	25.0
Nickel, Cold-Rolled	A-10.5	Annealed	144,400	87,000	71,500	43,000	43,000	15.8	23.0
Nickel, Cold-Rolled	A 11.0	Annealed	**142,600	**86,300	**70,300	**52,700	**50,000	**16.3	**24.8
Nickel, Cold-Rolled	A-11.5	Annealed	106,400	+	30,000	19,000	+	13.3	18.8
Nickel, Cold-Rolled	A-12.25	Annealed	*81,000	+	*22,000	*19,000	+	*29.0	*42.5
Nickel, Cold-Rolled	A-13.40	Annealed	72,500	+	16,500	7,500	+	42.0	50.5
Nickel, Cold-Rolled	A-14	Annealed	73,400	+	17,800	7,500	+	42.8	49.8
Nickel, Cold-Rolled	A-16	Annealed	70,400	+	14,300	6,000	+	47.8	54.8
Nickel, Cold-Rolled	CT	As Received	††115,800	††78,300	††77,100	††67,900	††61,900	††16.3	††36.9
Nickel, Cold-Rolled	CT-5.5	Annealed	**113,900	**77,300	**75,000	**56,000	**53,300	**16.3	**37.5
Nickel, Cold-Rolled	CT-7.5	Annealed	*109,000	*66,000	*70,000	*58,000	*54,000	*15.0	*35.5
Nickel, Cold-Rolled	CT-9.0	Annealed	*105,000	*68,000	*70,000	*60,000	*56,000	*19.5	*39.0
Nickel, Cold-Rolled	CT-10	Annealed	**101,800	**63,700	**65,000	**60,000	**56,700	**20.7	**42.7
Nickel, Cold-Rolled	CT-10.5	Annealed	*101,800	*66,000	*65,000	*55,000	*55,000	*20.5	*41.5
Nickel, Cold-Rolled	CT-11.0	Annealed	**100,500	**61,700	**62,300	*50,000	**45,300	**22.5	**49.7
Nickel, Cold-Rolled	CT-11.75	Annealed	*92,500	*56,000	*56,000	*44,000	*40,000	*23.0	*46.5
Nickel, Cold-Rolled	CT-12	Annealed	87,300	37,500	34,000	21,500	20,000	30.8	60.8
Nickel, Cold-Rolled	CT-12.5	Annealed	*75,000	+	*19,000	*12,500	+	*33.0	*60.5
Nickel, Cold-Rolled	CT-16.0	Annealed	†††72,400	+	†††11,900	††9,600	+	†††53.7	†††76.4
Nickel, Cold-Drawn	CRB	As Received	100,800	71,000	65,000	42,500	41,300	22.3	71.0
Nickel, Cold-Drawn	CRB-16	Annealed	78,000	16,000	16,300	15,000	13,000	54.8	79.0
Nickel, Cold-Drawn	CRA	As Received	94,000	64,000	55,000	31,500	27,500	22.5	70.3
Nickel, Cold-Drawn	CRA-16	Annealed	72,200	+	12,000	9,000	+	54.5	78.5
Nickel, Cold-Drawn	CR	As Received	84,300	62,500	54,000	35,000	27,500	23.3	74.0
Nickel, Cold-Drawn	CR-3.5	Annealed	*88,000	*73,000	*72,000	*60,000	*60,000	*22.5	*62.0
Nickel, Cold-Drawn	CR-5.5	Annealed	*92,000	*74,000	*74,500	*67,000	*67,000	*19.5	*43.5
Nickel, Cold-Drawn	CR-8.5	Annealed	*88,500	*63,000	*67,000	*61,000	*56,000	*22.0	*53.5
Nickel, Cold-Drawn	CR-9.5	Annealed	*85,800	*60,000	*62,600	*55,000	*50,000	*24.5	*53.0
Nickel, Cold-Drawn	CR-10.5	Annealed	*85,300	*60,000	*60,000	*55,000	*52,000	*28.0	*58.5
Nickel, Cold-Drawn	CR-11.5	Annealed	*83,800	*55,000	*57,500	*51,000	*48,000	*28.5	*58.0
Nickel, Cold-Drawn	CR-12.5	Annealed	*79,400	*50,000	*51,000	*47,000	*45,000	*32.0	*62.0
Nickel, Cold-Drawn	CR-13.0	Annealed	*78,000	*42,000	*45,000	*32,000	*23,000	*35.0	*72.5
Nickel, Cold-Drawn	CR-13.5	Annealed	*66,300	+	*13,000	*7,500	+	*56.0	*77.5
Nickel, Cold-Drawn	CR-14.0	Annealed	*66,500	+	*9,500	*5,000	+	*55.5	*76.5
Nickel, Cold-Drawn	CR-16	Annealed	63,800	+	27,500	22,000	+	57.3	80.3
Nickel, Hot-Rolled	AW	As Received	†76,200	†30,300	34,700	27,300	†25,100	†47.0	†69.0
Nickel, Hot-Rolled§	AW-14	Annealed	□75,900	□27,000	34,700	25,000	22,200	□47.9	□69.8
Nickel, Hot-Rolled✣	AWA	As Received	†60,100	†20,700	22,500	16,600	†16,500	†53.0	†74.2
Nickel, Hot-Rolled	AWB	As Received	*60,300	*19,000	*22,000	*15,000	*10,000		
Nickel, Hot-Rolled	AWB-14	Annealed	59,100	7,000	9,000	6,000	4,000	59.0	80.6

Material	Material Designation	Condition	Tensile Strength, Lbs. per Sq. In.	Johnson's Limit, Lbs. per Sq. In.	Proof Stress, Lbs. per Sq. In.	Elastic Limit, Lbs. per Sq. In.	Proportional Limit, Lbs. per Sq. In.	Elongation in 2 In., Per Cent	Reduction of Area, Per Cent
Monel Metal, Cold-Rolled	✣BH	As Received	**97,400	+	41,000	21,500	+	**28.5	**72.2
Monel Metal, Cold-Rolled	✣BH-16	Annealed	84,400	+	26,300	*15,000	+	50.0	76.1
Monel Metal, Cold-Drawn	CS	As Received	96,300	+	49,500	35,300	+	29.3	69.3
Monel Metal, Cold-Drawn	CS-3.5	Annealed	*97,000	+	*69,000	63,000	+	33.0	*74.0
Monel Metal, Cold-Drawn	CS-5.5	Annealed	97,700	+	76,500	63,000	+	28.3	67.0
Monel Metal, Cold-Drawn	CS-8.5	Annealed	*93,500	+	*64,000	*58,000	+	*30.5	*69.5
Monel Metal, Cold-Drawn	CS-9.0	Annealed	89,500	+	60,000	55,000	+	35.5	67.3
Monel Metal, Cold-Drawn	CS-9.5	Annealed	*94,500	+	*62,000	55,000	+	*36.5	*70.0
Monel Metal, Cold-Drawn	CS-10.5	Annealed	*89,000	+	*59,000	*54,000	+	*34.5	*70.5
Monel Metal, Cold-Drawn	CS-11.5	Annealed	*86,500	+	*53,000	*49,000	+	*37.0	*71.5
Monel Metal, Cold-Drawn	CS-12.5	Annealed	*85,000	+	*50,000	*46,000	+	*38.5	*71.0
Monel Metal, Cold-Drawn	CS-14.0	Annealed	**86,100	+	**34,800	**29,300	+	**45.0	**73.2
Monel Metal, Cold-Drawn	CS-16.0	Annealed	†81,100	+	†26,300	†23,600	+	†50.0	†75.0
Monel Metal, Hot-Rolled	AA	As Received	†90,200	†56,200	60,000	51,500	†42,700	†35.9	†69.7
Monel Metal, Hot-Rolled	AA-1	Annealed	77,300	+	30,000	22,500	+	48.0	73.0
Monel Metal, Cold-Rolled	BK	As Received	†88,300	+	34,500	15,000	+	†28.9	†57.3
Monel Metal, Cold-Rolled	BK-1	Annealed	77,100	+	21,300	15,000	+	48.0	64.3
Nickel-Copper-Manganese Alloy, Hot-Rolled	C	As Received	91,600	+	27,500	9,300	+	47.5	66.5
Nickel-Copper-Manganese Alloy, Hot-Rolled	C-16	Annealed	88,800	35,000	35,000	31,000	29,000	49.0	70.0
Copper-Nickel Alloy, Hot-Rolled	CU	As Received	65,400	22,800	23,300	19,600	17,300	47.0	77.5
Copper-Nickel Alloy, Hot-Rolled	CU-15	Annealed	62,100	18,500	20,300	....	14,500	50.0	77.7
Constantan, Cold-Rolled	CV	As Received	103,300	+	54,700	32,400	+	*14.8	*70.1
Constantan, Cold-Rolled	CV-3.5	Annealed	*103,500	+	*73,000	*24,000	+	*17.5	*67.5
Constantan, Cold-Rolled	CV-5.5	Annealed	*106,000	+	*67,000	*31,000	+	*16.5	*68.5
Constantan, Cold-Rolled	CV-8.5	Annealed	*99,100	+	*71,000	*32,000	+	*23.0	*70.0
Constantan, Cold-Rolled	CV-9.5	Annealed	*96,900	+	*72,000	*65,000	+	*24.0	*71.0
Constantan, Cold-Rolled	CV-10.5	Annealed	*96,300	+	*70,000	*62,000	+	*25.5	*72.0
Constantan, Cold-Rolled	CV-11.5	Annealed	*71,800	+	*29,500	*27,000	+	*48.0	*79.0
Constantan, Cold-Rolled	CV-12.5	Annealed	*70,500	+	*28,500	*26,000	+	*48.0	*78.0
Constantan, Cold-Rolled	CV-14	Annealed	*69,000	+	*25,500	*22,500	+	*48.0	*80.0
Constantan, Cold-Rolled	CV-14.5	Annealed	69,400	24,500	25,400	23,800	21,000	48.3	79.0
Constantan, Hot-Rolled	CE	As Received	70,500	27,000	28,000	25,000	14,500	48.5	78.5
Constantan, Hot-Rolled	CE-1	Annealed	70,300	27,500	26,500	19,000	14,000	48.8	79.3
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	As Received	87,300	+	55,500	13,300	+	3.8	22.0
Copper-Nickel-Tin Alloy, Cold-Drawn	CF-1	Annealed	57,800	+	16,300	9,000	+	*33.0	*51.5
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD	As Received	57,100	+	32,000	21,500	+	35.8	69.8
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD-1	Annealed	51,100	+	12,300	6,500	+	47.3	72.7
Copper-Nickel Alloy, Cold-Rolled	B	As Received	49,900	+	30,000	14,000	+	36.0	67.5
Copper-Nickel Alloy, Cold-Rolled	B-1	Annealed	44,400	+	9,000	5,000	+	48.8	70.9
Copper, Cold-Rolled	BO	As Received	40,400	+	*13,000	*5,000	+	24.5	66.0
Copper, Cold-Drawn	CL	As Received	40,400	+	19,000	5,000	+	27.0	66.8
Copper, Cold-Drawn	CL-1	Annealed	31,500	+	4,200	2,000	+	58.3	75.8
Copper, Hot-Rolled	BU	As Received	**31,400	+	6,500	3,700	+	58.7	72.2

✣BH was BH-1 in Part I and II.
✣BH-16 was BH-2 in Part I and II.

stress-cycle relationship is similar to that of material A as shown in Fig. 1 of Part II. Beyond an abscissa of 30 million cycles, the slope of the curve is slight and indicates the approximate endurance limit. Beyond an abscissa of 50 million cycles the curve is evidently nearly horizontal.

The curves for the same material after annealing at 1000 and 1100 degrees Fahr. respectively are similar in form to the curve for the material as received. The endurance limit as indicated by the upper three curves of Fig. 1 is not lowered by annealing to any temperature up to 1100 degrees Fahr., although the tensile strength is lowered considerably by annealing at 1000 to 1100 degrees Fahr. The endurance limit of the material annealed at 1000 degrees Fahr. is apparently even higher than that of the material as received. In this respect, material CT resembles material A discussed in Part II, although the phenomenon is more conspicuous in the more severely cold-worked material.

As shown in the lower graph of Fig. 1, annealing at 1600 degress Fahr. lowers the endurance limit and decreases the slope of the stress-cycle graph.

The results illustrated in Fig. 1 show that the "endurance ratio" of the cold-worked material CT is lower than that of the same material annealed at 1000 degrees Fahr. or higher. Evidently, therefore, cold working sufficient to increase the tensile strength 60 per cent lowers the endurance ratio. As might be expected the lowering of the endurance ratio of this material by cold working is less than that of the more severely cold-worked material A discussed in Part II.

The effect of temperature of anneal on endurance properties, as well as other physical properties of material CT is illustrated in Fig. 5. The relationship of the graphs of endurance limits and endurance ratios to the graph of tensile strength should be noted. The relationship is similar to that shown for material A in Fig. 2 of Part II.

Stress-cycle Graphs for Materials CRB, CRA and CR

Results of rotating-cantilever endurance tests on cold drawn nickel, materials CRB, CRA and CR, are illustrated graphically in Fig. 2. These three materials had received the same amount of cold working, but were of different composition, and showed different tensile properties in the annealed condition.

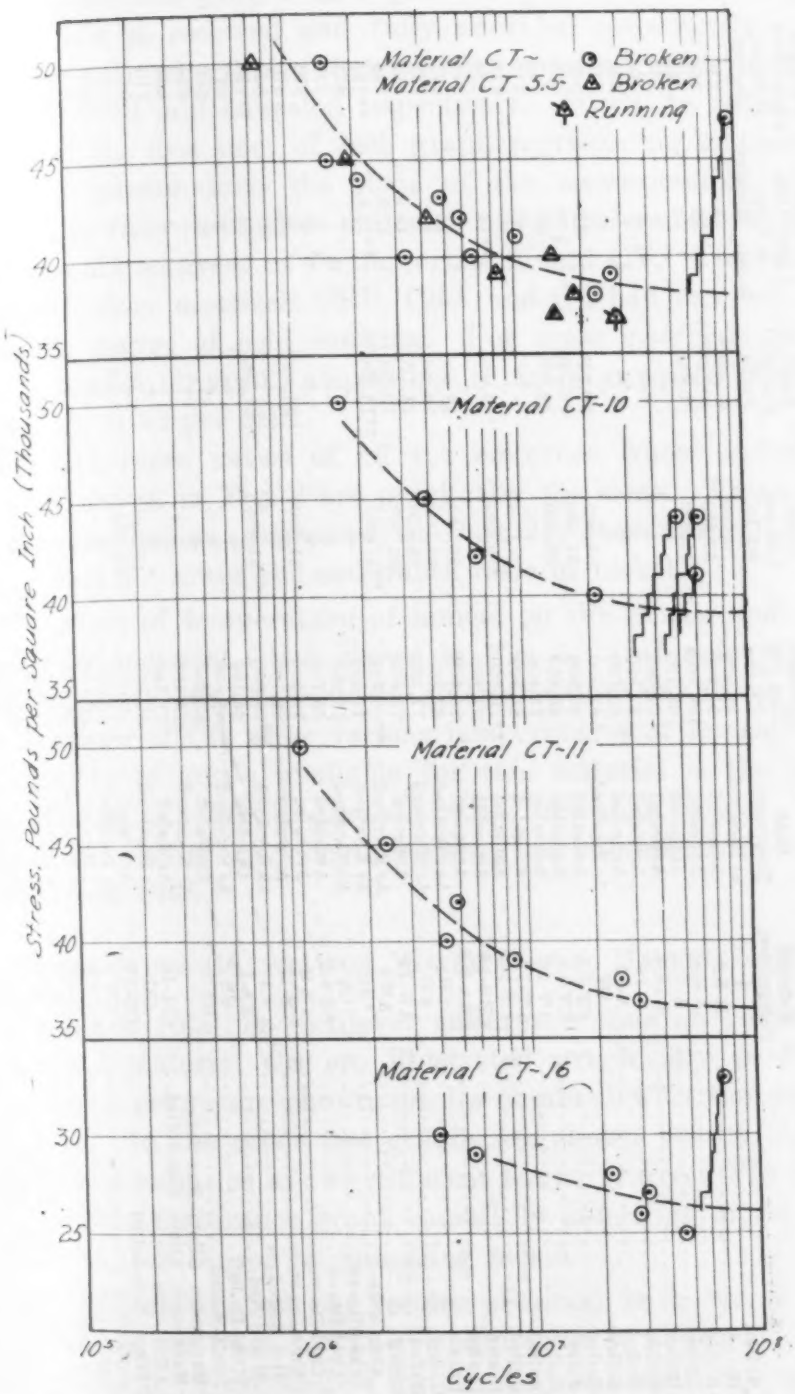


Fig. 1—Graphs Showing Effect of Cold Rolling and Annealing on the Endurance Properties of Nickel, Material CT.

Table III
Results of Static Torsion Tests
Individual Results, Except as Noted

Material	Material Designation	Heat Treatment	Nominal Torsional Strength, Lbs. per Sq. In.	Johnson's Limit, Lbs. per Sq. In.	Proportional Limit, Lbs. per Sq. In.	Angle of Twist per Linear Inch, at Prop. Limit, Minutes	Angle of Twist per Linear Inch at Break, Degrees
Nickel, Cold-Rolled	A	As Received	96,900	70,000	67,600	58	230
Nickel, Cold-Rolled	A-5.5	Annealed	96,900	67,600	50,700	39	163
Nickel, Cold-Rolled	A-8.5	Annealed	106,900	74,900	70,000	50	332
Nickel, Cold-Rolled	A-11	Annealed	66,100	+	+	+	123
Nickel, Cold-Rolled	A-13.4	Annealed	61,600	+	+	+	403
Nickel, Cold-Rolled	A-14	Annealed	57,100	+	+	+	408
Nickel, Cold-Rolled	A-16	Annealed	55,700	+	+	+	348
Nickel, Cold-Rolled	CT	As Received	81,500	58,000	36,200	75	550
Nickel, Cold-Rolled	CT-5.5	Annealed	85,600	58,000	50,700	120	623
Nickel, Cold-Rolled	CT-10	Annealed	88,800	36,200	36,200	90	747
Nickel, Cold-Rolled	CT-11	Annealed	73,400	+	+	+	710
Nickel, Cold-Rolled	CT-12	Annealed	81,500	+	+	+	713
Nickel, Cold-Rolled	CT-16	Annealed	**75,200	**9,660	**9,660	**19	754
Nickel, Cold-Drawn	CRB-16	Annealed	84,200	+	+	+	878
Nickel, Cold-Drawn	CRA-8.5	Annealed	82,400	50,700	48,300	35	677
Nickel, Cold-Drawn	CR	As Received	67,000	41,100	36,200	30	720
Nickel, Hot-Rolled	AW	As Received	71,100	26,600	21,700	13.5	798
Nickel, Hot-Rolled	AW-14	Annealed	73,400	21,700	19,300	17.0	798
Nickel, Hot-Rolled	AWa	As Received	**66,800	**17,800	**18,300	**12.8	**819
Monel Metal, Cold-Rolled	*BH	As Received	77,300	+	+	+	874
Monel Metal, Cold-Drawn	CS	As Received	77,000	+	+	+	770
Monel Metal, Cold-Drawn	CS-5.5	Annealed	69,700	+	+	+	596
Monel Metal, Cold-Drawn	CS-9	Annealed	70,500	41,000	33,800	95	826
Monel Metal, Cold-Drawn	CS-16	Annealed	69,700	+	+	+	860
Monel Metal, Hot-Rolled	AA	As Received	**69,000	**31,900	**27,700	**24	**746
Monel Metal, Hot-Rolled	AA-1	Annealed	66,100	+	+	+	687
Monel Metal, Cold-Rolled	BK	As Received	65,000	+	+	+	560
Monel Metal, Cold-Rolled	BK-1	Annealed	67,900	+	+	+	634
Nickel-Copper-Manganese Alloy, Hot-Rolled	C	As Received	73,400	+	+	+	665
Nickel-Copper-Manganese Alloy, Hot-Rolled	C-1-16	Annealed	78,340	+	+	+	710
Copper-Nickel-Alloy, Hot-Rolled	CU	As Received	59,800	19,300	9,700	10	923
Copper-Nickel-Alloy, Hot-Rolled	CU-15	Annealed	58,000	14,500	9,700	7	927
Constantan, Cold-Rolled	CV	As Received	65,000	+	+	+	820
Constantan, Cold-Rolled	CV-14.5	Annealed	55,700	+	+	+	914
Constantan, Hot-Rolled	CE	As Received	66,100	+	+	+	976
Constantan, Hot-Rolled	CE-1	Annealed	60,200	+	+	+	1073
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	As Received	48,000	+	+	+	495
Copper-Nickel-Tin Alloy, Cold-Drawn	CF-1	Annealed	47,000	+	+	+	677
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD	As Received	45,300	+	+	+	819
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD-1	Annealed	43,900	+	+	+	867
Copper-Nickel Alloy, Cold-Rolled	B	As Received	41,700	+	+	+	753
Copper-Nickel Alloy, Cold-Rolled	B-1	Annealed	43,470	+	+	+	795
Copper, Cold-Rolled	BD	As Received	41,999	+	+	+	799
Copper, Cold-Rolled	BD	Annealed	31,999	+	+	+	1000

The upper two graphs in Fig. 2 show results obtained with material CRB as received and fully annealed respectively. The next lower pair of graphs show results obtained with material CRA as received and annealed respectively. It will be noted that the slope of the first part of each graph representing material as received is greater than the slope of the corresponding graph representing fully annealed material. The difference in slope, however, is not so great as for materials A and CT. This was to be expected, since materials CRB, CRA and CR had received only a moderate degree of cold working. For these materials the increase in tensile strength, above that of fully annealed material, was only about 32 per cent.

The endurance ratios of all the materials whose endurance graphs are shown in Fig. 2 are practically the same. This agrees with the conclusions, expressed in Part II, that moderate cold working does not lower the endurance ratio of nickel.

The effect of temperature of anneal on the tensile and shear properties of material CR is shown in Fig. 6. Unfortunately not enough material was available to determine the endurance properties of material CR after various temperatures of anneal. The only stress-cycle graph available for this material is the lowest graph of Fig. 2. The endurance ratio indicated in Fig. 6 for material annealed at 1600 degrees Fahr. was obtained from materials CRB and CRA.

Stress-cycle Graphs for Monel Metal, Material CS

Results of rotating-cantilever endurance tests on cold-drawn monel metal material CS are illustrated graphically in Fig. 3. In the upper graph are shown results obtained with the material as received. In the other two graphs are shown results obtained with material annealed at two different temperatures. The change in slope of the endurance graph caused by annealing monel metal is similar to that caused by annealing nickel.

The irregularity of the results obtained with monel metal was mentioned in Part I. This irregularity is noticeable in the graphs of Fig 3. Nevertheless the stress-cycle graphs representing average endurance properties are accurate enough to show that the endurance ratio is practically unaffected by the moderate cold working of this material. The cold working was sufficient to in-

crease the tensile strength only 15 per cent above that of fully annealed material.

The zig-zag line at the right of the upper graph of Fig. 3, as well as the similar lines at the right of most of the graphs of Figs. 1 and 2, have the significance described in Parts I and II. The great increases of stress endured by some of these specimens after having endured many million cycles at the original stress indicates that the graphs as drawn point to the "endurance limits" of the material.

The effect of annealing temperature on endurance properties as well as on other physical properties of the cold-drawn monel metal, material CS, is illustrated in Fig. 7. The endurance-limit graph in Fig. 7 is incomplete, but the probable course of this graph between abscissas of 550 and 1600 degrees Fahr. is indicated by a broken line.

Stress-cycle Graphs for Constantan, Material CV

Results of endurance tests on cold-rolled constantan are shown in Fig. 4. In the upper graph are shown results obtained with the material as received. In the lower graph are shown results obtained with the same material fully annealed. The difference in slope of the two graphs is conspicuous. Although the tensile strength of the material as received is 47 per cent greater than that of fully annealed material the "endurance ratios" of the material as-received and of fully annealed material are practically the same.

Effect of Temperature of Anneal on Physical Properties of Cold-Rolled Nickel, Material CT

Fig. 5 illustrates the effect of temperature of anneal on tensile strength, "proof stress," elastic limit, rotating-cantilever endurance limit, shearing strength, ratio of shearing strength to tensile strength, and rotating-cantilever endurance ratio of cold-rolled nickel. As shown in this figure, during the temperature range of recrystallization the tensile strength, proof stress, elastic limit, and shearing strength decrease rapidly. The slope of these graphs increases rapidly between abscissas of about 600 and 1200 degrees Fahr. The curve of endurance limits, however, remains horizontal up to an abscissa of about 1000 degrees Fahr. then rises slightly,

and from this point slopes downward nearly parallel to the curve of tensile strength.

The curve representing ratio of shearing strength to tensile strength, however, is practically the reverse in form of the curve of tensile strength. A curve representing ratio of tensile strength to shearing strength would have the same form as the curve of tensile strength.

The curve of endurance ratios rises rapidly at an abscissa corresponding approximately to the temperature of incipient recrystallization.

Effect of Temperature of Anneal on Physical Properties of Cold-Drawn Nickel, Material CR

Fig. 6 illustrates the effect of temperature of anneal on physical properties of nickel that had been less severely cold-worked than material CT. As in Fig. 5 the graphs in Fig. 6 representing tensile strength, proof stress, elastic limit, and shearing strength, slope rapidly throughout the temperature range of recrystallization. There is only one point representing endurance limit. Since results obtained with materials CRB and CRA have shown that the endurance ratio of such moderately cold-worked material is unaffected by annealing, the lack of a complete endurance-limit graph and a complete endurance-ratio graph is unimportant.

The curve representing ratio of shearing strength to tensile strength rises rapidly at the abscissa of greatest downward slope of the curves of tensile strength, proof stress and elastic limit.

Effect of Temperature of Anneal on Physical Properties of Cold-Drawn Monel Metal, Material CS

Fig. 7 illustrates the effect of temperature of anneal on physical properties of cold-drawn monel metal. This material had been cold-worked enough to increase the tensile strength only 15 per cent above that of fully annealed material. Corresponding to the relatively slight amount of cold working that this material received, the total drop in the graphs of tensile strength and shearing strength is much less than for materials CT and CR. Under these conditions the above mentioned slight non-uniformity in physical properties of this material is sufficient to mask the effect of temperature on the ratio of shearing strength to tensile strength. For this reason a curve has not been drawn to represent this ratio.

Table IV
Relationship of Shearing Strength to Tensile Strength

Material	Material Designation	Tensile Strength, Lbs. per Sq. In.	Shearing Strength, Lbs. per Sq. In.	Ratio of Col. 4 to Col. 3
1	2	3	4	5
Nickel, Cold-Rolled	A	166,200	94,900	0.57
Nickel, Cold-Rolled	A-5.5	165,500	94,900	0.57
Nickel, Cold-Rolled	A-8.5	160,000	91,500	0.57
Nickel, Cold-Rolled	A-9.5	150,300	90,200	0.60
Nickel, Cold-Rolled	A-10.0	151,500	85,900	0.57
Nickel, Cold-Rolled	A-10.5	144,400	85,800	0.59
Nickel, Cold-Rolled	A-11	142,600	83,700	0.58
Nickel, Cold-Rolled	A-11.5	106,400	62,200	0.58
Nickel, Cold-Rolled	A-12.25	81,000	56,100	0.69
Nickel, Cold-Rolled	A-13.40	72,500	52,900	0.73
Nickel, Cold-Rolled	A-14	73,400	53,000	0.72
Nickel, Cold-Rolled	A-16	70,400	50,400	0.71
Nickel, Cold-Rolled	CT	115,800	65,500	0.58
Nickel, Cold-Rolled	CT-5.5	113,900	70,900	0.63
Nickel, Cold-Rolled	CT-7.5	109,000	67,700	0.59
Nickel, Cold-Rolled	CT-9.0	105,000	66,700	0.64
Nickel, Cold-Rolled	CT-10	101,800	67,600	0.66
Nickel, Cold-Rolled	CT-10.5	101,800	64,900	0.64
Nickel, Cold-Rolled	CT-11.0	100,500	65,400	0.65
Nickel, Cold-Rolled	CT-11.75	92,500	63,000	0.68
Nickel, Cold-Rolled	CT-12	87,300	59,600	0.68
Nickel, Cold-Rolled	CT-12.5	75,000	55,700	0.74
Nickel, Cold-Rolled	CT-16	72,400	51,900	0.72
Nickel, Cold-Drawn	CR	84,300	57,500	0.68
Nickel, Cold-Drawn	CR-3.5	88,000	58,400	0.66
Nickel, Cold-Drawn	CR-5.5	92,000	.....	...
Nickel, Cold-Drawn	CR-8.5	88,500	58,100	0.66
Nickel, Cold-Drawn	CR-9.5	85,800	57,400	0.67
Nickel, Cold-Drawn	CR-10.5	85,300	57,400	0.67
Nickel, Cold-Drawn	CR-11.5	83,800	56,300	0.67
Nickel, Cold-Drawn	CR-12.5	79,400	53,500	0.67
Nickel, Cold-Drawn	CR-13.0	78,000	51,400	0.66
Nickel, Cold-Drawn	CR-13.5	66,300	52,200	0.79
Nickel, Cold-Drawn	CR-14	66,500	49,800	0.75
Nickel, Cold-Drawn	CR-16	63,800	49,700	0.78
Monel Metal, Cold-Drawn	CS	96,300	66,500	0.71
Monel Metal, Cold-Drawn	CS-3.5	97,000	67,700	0.69
Monel Metal, Cold-Drawn	CS-5.5	97,700	64,300	0.66
Monel Metal, Cold-Drawn	CS-8.5	93,500	67,600	0.72
Monel Metal, Cold-Drawn	CS-9.0	89,500	61,800	0.69
Monel Metal, Cold-Drawn	CS-9.5	94,500	66,000	0.69
Monel Metal, Cold-Drawn	CS-10.5	89,000	65,700	0.74
Monel Metal, Cold-Drawn	CS-11.5	86,500	60,000	0.69
Monel Metal, Cold-Drawn	CS-12.5	85,000	59,800	0.70
Monel Metal, Cold-Drawn	CS-14.0	86,100	57,400	0.66
Monel Metal, Cold-Drawn	CS-16.0	81,100	55,400	0.68
Constantan, Cold-Rolled	CV	103,300	59,400	0.57
Constantan, Cold-Rolled	CV-3.5	103,500	59,300	0.57
Constantan, Cold-Rolled	CV-5.5	106,000	61,500	0.58
Constantan, Cold-Rolled	CV-8.5	99,100	59,400	0.60
Constantan, Cold-Rolled	CV-9.5	96,900	59,000	0.60
Constantan, Cold-Rolled	CV-10.5	96,300	58,700	0.60
Constantan, Cold-Rolled	CV-11.5	71,800	49,400	0.68
Constantan, Cold-Rolled	CV-12.5	70,500	50,200	0.71
Constantan, Cold-Rolled	CV-14	69,000	49,000	0.71
Constantan, Cold-Rolled	CV-14.5	69,400	49,900	0.72

Effect of Temperature of Anneal on Physical Properties of Cold-Rolled Constantan, Material CV

Fig. 8 illustrates the effect of temperature of anneal on physical properties of cold-rolled constantan, material CV. The degree of cold working was sufficient to increase the tensile strength about

Table V
Annealing Treatment

Material	Material Designation	Heated to Deg. Fahr.	Time Held, Min.	Cooled in
Nickel, Cold-Rolled	A-5.5	550	60	Furnace
Nickel, Cold-Rolled	A-8.5	850	60	Furnace
Nickel, Cold-Rolled	A-9.5	950	60	Furnace
Nickel, Cold-Rolled	A-10.0	1000	60	Furnace
Nickel, Cold-Rolled	A-10.5	1050	60	Air
Nickel, Cold-Rolled	A-11.0	1100	60	Furnace
Nickel, Cold-Rolled	A-11.5	1150	60	Air
Nickel, Cold-Rolled	A-12.25	1225	60	Air
Nickel, Cold-Rolled	A-13.4	1340	60	Furnace
Nickel, Cold-Rolled	A-14.0	1400	60	Furnace
Nickel, Cold-Rolled	A-16.0	1600	60	Furnace
Nickel, Cold-Rolled	CT-5.5	550	60	Furnace
Nickel, Cold-Rolled	CT-7.5	750	60	Air
Nickel, Cold-Rolled	CT-9.0	900	60	Air
Nickel, Cold-Rolled	CT-10.0	1000	60	Air
Nickel, Cold-Rolled	CT-10.5	1050	60	Air
Nickel, Cold-Rolled	CT-11.0	1100	60	Furnace
Nickel, Cold-Rolled	CT-11.75	1175	60	Air
Nickel, Cold-Rolled	CT-12.0	1200	60	Furnace
Nickel, Cold-Rolled	CT-12.5	1250	60	Air
Nickel, Cold-Rolled	CT-16.0	1600	60	Furnace
Nickel, Cold-Drawn	CRB-16	1600	60	Furnace
Nickel, Cold-Drawn	CRA-16	1600	60	Furnace
Nickel, Cold-Drawn	CR-3.5	350	60	Air
Nickel, Cold-Drawn	CR-5.5	550	60	Air
Nickel, Cold-Drawn	CR-8.5	850	60	Air
Nickel, Cold-Drawn	CR-9.5	950	60	Air
Nickel, Cold-Drawn	CR-10.5	1050	60	Air
Nickel, Cold-Drawn	CR-11.5	1150	60	Air
Nickel, Cold-Drawn	CR-12.5	1250	60	Air
Nickel, Cold-Drawn	CR-13.0	1300	60	Air
Nickel, Cold-Drawn	CR-13.5	1350	60	Air
Nickel, Cold-Drawn	CR-14.0	1400	60	Air
Nickel, Cold-Drawn	CR-16.0	1600	60	Furnace
Nickel, Hot-Rolled	AW-14	1400	60	Furnace
Nickel, Hot-Rolled	AWb-14	1400	60	Furnace
Monel Metal, Cold-Rolled	BH-16	1600	60	Furnace
Monel Metal, Cold-Drawn	CS-3.5	350	60	Furnace
Monel Metal, Cold-Drawn	CS-5.5	550	60	Furnace
Monel Metal, Cold-Drawn	CS-8.5	850	60	Air
Monel Metal, Cold-Drawn	CS-9.0	900	60	Furnace
Monel Metal, Cold-Drawn	CS-9.5	950	60	Air
Monel Metal, Cold-Drawn	CS-10.5	1050	60	Air
Monel Metal, Cold-Drawn	CS-11.5	1150	60	Air
Monel Metal, Cold-Drawn	CS-12.5	1250	60	Air
Monel Metal, Cold-Drawn	CS-14.0	1400	60	Furnace
Monel Metal, Cold-Drawn	CS-16.0	1600	60	Furnace
Monel Metal, Hot-Rolled	AA-1	1600	60	Furnace
Monel Metal, Cold-Rolled	BK-1	1600	60	Furnace
Nickel-Copper-Manganese Alloy, Hot-Rolled	C-16	1600	60	Furnace
Copper-Nickel Alloy, Hot-Rolled	CU-15	1500	60	Furnace
Constantan, Cold-Rolled	CV-3.5	350	60	Air
Constantan, Cold-Rolled	CV-5.5	550	60	Air
Constantan, Cold-Rolled	CV-8.5	850	60	Air
Constantan, Cold-Rolled	CV-9.5	950	60	Air
Constantan, Cold-Rolled	CV-10.5	1050	60	Air
Constantan, Cold-Rolled	CV-11.5	1150	60	Air
Constantan, Cold-Rolled	CV-12.5	1250	60	Air
Constantan, Cold-Rolled	CV-14	1400	60	Air
Constantan, Cold-Rolled	CV-14.5	1450	60	Furnace
Constantan, Hot-Rolled	CE-1	1450	60	Furnace
Copper-Nickel-Tin Alloy, Cold-Drawn	CF-1	1500	60	Furnace
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD-1	1400	60	Furnace
Copper-Nickel Alloy, Cold-Rolled	B-1	1400	60	Furnace
Copper, Cold-Drawn	CL-1	1200	60	Furnace

47 per cent above that of fully annealed material. The curves of tensile strength, proof stress and shearing strength are similar in form to the corresponding curves shown in Figs. 5, 6 and 7. The temperature of greatest slope, however, is lower for constantan than for nickel and monel metal. Since only two points are available a curve of endurance limits could not be drawn. The curve representing ratio of shearing strength to tensile strength is nearly the reverse in form of the curve representing tensile strength.

Effect of Temperature of Anneal on Physical Properties of Cold-Rolled Nickel, Material A

The fact that for cold-worked materials CT, CR, CS and CV as shown in Figs. 5, 6 and 8, the curves representing ratio of shearing strength to tensile strength rise with increase of temperature of anneal is of sufficient interest to justify the plotting of a similar graph for the more severely cold-worked nickel, material A, whose properties are illustrated in Fig. 2 of Part II. For this reason the curve representing effect of temperature of anneal on the ratio of shearing stress to tensile stress is presented in Fig. 9 in comparison with the curves of shearing strength, endurance limit and endurance ratio.

As in Figs. 5, 6 and 8 there is an abrupt rise in the curve of ratio of shearing stress to tensile stress at about the abscissa of greatest slope of the curve of endurance ratios. It should be noted that in Figs. 5, 6, 8 and 9 the ratio of shearing strength to tensile strength for material in the fully annealed condition is between about 0.72 and 0.78. This ratio for the material as received, however, varies with the degree of cold working. It is lower for severely cold-worked materials A and CT than for material CV. For the slightly cold-worked material CS it is probable that this ratio is slightly lower in the "as received" condition than in the annealed condition. The difference, however, is slight enough to be masked by the slight non-uniformity of the monel metal.

Effect of Degree of Cold Working on Rotating-Cantilever Endurance Properties

Quantitative Index of Degree of Cold Working

For a quantitative index of the degree of cold working it has been found convenient to use the percentage increase in tensile

strength of the cold-worked material above the tensile strength of the annealed material. Brief reference has been made to this index in discussion of Figs. 1 to 8 inclusive. The index, however, is useful in studying quantitatively the effect of degree of cold working on rotating-cantilever endurance properties.

Variation of Endurance Properties of Nickel with Degree of Cold Working

Using the above described quantitative index as abscissa and rotating-cantilever endurance properties as ordinate a series of graphs has been drawn in Fig. 10 to represent the variation of endurance properties of nickel with degree of cold working. The upper graph in Fig. 10 represents approximately the effect of cold working on the rotating-cantilever endurance limit of nickel. As shown in this graph, the increase in the endurance limit by cold working becomes gradually less rapid with increase in the degree of cold working. Beyond a "cold working" index of about 60 per cent the curve becomes nearly horizontal.

Influencing somewhat the upper curve of Fig. 10 there are effects of variables other than degree of cold working. Variation of chemical composition has considerable influence on such a curve. To eliminate this variable, the next lower curve has been drawn with ordinates representing percentage increase of endurance limit of cold-worked material above that of the same material when fully annealed. This graph evidently starts from the origin at an angle of 45 degrees and continues in this direction until an abscissa of nearly 40 is reached. It then begins to curve and gradually approaches a horizontal direction between abscissas of 60 and 136. The reason that one experimental point is considerably above this line is due to the fact that a sample of nickel had an abnormally low endurance limit in the annealed condition.

The curve of endurance ratios is practically horizontal until an abscissa between 30 and 40 is reached. It then begins to curve downward and between abscissas of 60 and 136 is a nearly straight downward sloping line.

The lowest graph in Fig. 10 represents the influence of cold working on the ratio of shearing strength to tensile strength. This curve is nearly the reverse in form of the upper two curves of the figure. Evidently if a curve representing ratio of tensile

Table VI

Relationship of Endurance Limits to Other Physical Properties

Material	Material Designation	Cooled in	Drawn at Deg. Fahr.	Average Tensile Strength, Lbs. per Sq. In.	Average Torsional Strength, Lbs. per Sq. In.	Average Shearing Strength, Lbs. per Sq. In.
1	2	3	4	5	6	7
Nickel, Cold-Rolled	xA	As Received		**166,200	*96,900	94,900
Nickel, Cold-Rolled	A-5.5	Annealed		165,500	*96,900	94,900
Nickel, Cold-Rolled	A-8.5	Annealed		160,000	*106,900	91,500
Nickel, Cold-Rolled	A-11	Annealed		**142,600	*66,100	83,700
Nickel, Cold-Rolled	A-13.4	Annealed		72,500	*61,600	52,900
Nickel, Cold-Rolled	A-14	Annealed		73,400	*57,100	53,000
Nickel, Cold-Rolled	A-16	Annealed		70,400	*55,700	50,400
Nickel, Cold-Rolled	CT	As Received		†††115,800	*81,500	65,500
Nickel, Cold-Rolled	CT-5.5	Annealed		**113,900	*85,600	70,900
Nickel, Cold-Rolled	CT-10	Annealed		*101,500	*88,800	67,600
Nickel, Cold-Rolled	CT-11	Annealed		100,500	*73,400	65,400
Nickel, Cold-Rolled	CT-12	Annealed		87,300	*81,500	59,600
Nickel, Cold-Rolled	CT-16.0	Annealed		††72,400	75,200	51,900
Nickel, Cold-Drawn	CRB	As Received		100,800	.....	65,600
Nickel, Cold-Drawn	CRB-16	Annealed		78,000	*84,200	55,900
Nickel, Cold-Drawn	CRA	As Received		94,000	.....	62,100
Nickel, Cold-Drawn	CRA-16	Annealed		72,200	.....	52,700
Nickel, Cold-Drawn	CR	As Received		84,500	*67,000	57,500
Nickel, Cold-Drawn	CR-16	Annealed		63,800	.....	*49,700
Nickel, Hot-Rolled	‡AW	As Received		*76,200	*71,100	*55,100
Nickel, Hot-Rolled	AW-14	Annealed		†75,900	*73,400	56,100
Nickel, Hot-Rolled	AWa	As Received		†60,100	*66,300	*43,500
Nickel, Hot-Rolled	AWb	As Received		*60,500	.....	46,900
Nickel, Hot-Rolled	‡AWb-14	Annealed		59,100	.....	.....
Monel Metal, Cold-Rolled	§BH	As Received		**97,400	77,300	67,200
Monel Metal, Cold-Rolled	‖BH-16	Annealed		84,400	.....	61,000
Monel Metal, Cold-Drawn	CS	As Received		†93,500	*77,000	66,500
Monel Metal, Cold-Drawn	....	.....		.....	.....	.....
Monel Metal, Cold-Drawn	CS-5.5	Annealed		*97,500	*67,900	64,300
Monel Metal, Cold-Drawn	....	.....		.....	.....	.....
Monel Metal, Cold-Drawn	CS-9.0	Annealed		89,500	*70,500	61,800
Monel Metal, Cold-Drawn	CS-16.0	Annealed		†81,100	*69,700	*55,400
Monel Metal, Hot-Rolled	AA	As Received		†90,200	69,000	59,400
Monel Metal, Hot-Rolled	AA-1	Annealed		77,300	66,100	56,900
Monel Metal, Cold-Rolled	BK	As Received		†88,300	*65,000	61,700
Monel Metal, Cold-Rolled	BK-1	Annealed		77,100	*67,900	55,300
Nickel-Copper-Manganese Alloy, Hot-Rolled	C	As Received		91,600	*73,400	65,800
Nickel-Copper-Manganese Alloy, Hot-Rolled	C-16	Annealed		88,800	*78,300	60,000
Copper-Nickel Alloy, Hot-Rolled	CU	As Received		**65,400	*59,800	47,500
Copper-Nickel Alloy, Hot-Rolled	CU-15	Annealed		62,100	*58,000	47,100
Constantan, Cold-Rolled	CV	As Received		103,300	*65,000	59,400
Constantan, Cold-Rolled	CV-14.5	Annealed		69,400	*55,700	49,900
Constantan, Hot-Rolled	CE	As Received		70,500	*66,100	50,000
Constantan, Hot-Rolled	CE-1	Annealed		70,300	*60,200	50,400
Copper-Nickel-Tin Alloy, Cold-Drawn	CF	As Received		87,300	*48,000	50,900
Copper-Nickel-Tin Alloy, Cold-Drawn	CF-1	Annealed		57,800	*47,000	42,100
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD	As Received		57,100	*45,300	**38,700
Copper-Nickel-Zinc Alloy, Hot-Rolled	CD-1	Annealed		51,100	*43,900	35,600
Copper-Nickel Alloy, Cold-Rolled	B	As Received		49,900	*41,700	35,300
Copper-Nickel Alloy, Cold-Rolled	B-1	Annealed		44,400	*43,500	33,300
Copper, Cold-Rolled	BO	As Received		40,400	*34,000	25,800
Copper, Cold-Drawn	CL	As Received		40,400	*31,000	27,200
Copper, Cold-Drawn	CL-1	Annealed		31,500	.....	21,500
Copper, Hot-Rolled	BU	As Received		**31,400	*29,900	23,900

Each static value is average of two specimens except as indicated. *One determination only, of three determinations. †Average of four determinations. ††Average of six determinations. mination from 12 in. gage length specimen. □One determination from 2 in. gage length +Calculated from results obtained with some material as received. †††Average of seven dete

Table VI—Continued

Relationship of Endurance Limits to Other Physical Properties

Limit, Lb. per Sq. In.	Static Ratios	Endurance Ratios						Brinell Hardness No.
Alternating Torsion	Column 6 to Column 5	Column 7 to Column 5	Column 10 to Column 9	Column 9 to Column 5	Column 10 to Column 5	Column 10 to Column 6	Column 10 to Column 7	
10	11	12	13	14	15	16	17	
.....	0.58	0.57	...	0.24	...	...	...	302
18,500	0.58	0.57	0.46	0.24	0.11	0.19	0.19	302
.....	0.67	0.57	...	0.25	...	...	...	302
.....	0.46	0.59	...	0.34	...	...	...	255
.....	0.85	0.73	...	...	...	...	...	96
.....	0.78	0.72	...	0.37	...	...	...	96
17,000	0.79	0.72	0.67	0.36	0.24	0.31	0.34	93
15,000	0.70	0.57	0.39	0.32	0.13	0.18	0.23	217
.....	0.74	0.62	...	0.33	...	...	...	207
.....	0.87	0.67	...	0.38	...	...	...	187
.....	0.73	0.65	...	0.36	...	...	...	187
.....	0.93	0.68	...	...	...	...	...	134
19,000	1.03	0.72	0.73	0.36	0.26	0.25	0.36	109
.....	...	0.65	...	0.37	...	...	...	185
.....	1.08	0.71	...	0.37	...	...	...	83
.....	...	0.66	...	0.39	...	...	...	165
.....	...	0.73	...	0.31	...	...	...	86
.....	0.79	0.68	...	0.40	...	...	...	163
.....	...	0.78	...	0.40	...	...	...	86
20,000	0.93	0.72	...	...	0.33	0.28	0.46	†105
.....	0.97	0.74	...	0.42	...	...	...	74
.....	1.18	0.72	...	0.40	...	...	...	89
.....	...	0.78	...	...	...	...	...	89
.....	...	...	...	...	...	...	...	65
.....	0.79	0.69	...	0.35	...	...	...	100
.....	...	0.72	...	0.35	...	...	...	100
.....	0.82	0.71	...	0.37	...	...	...	158
.....	...	...	...	...	...	...	...	...
.....	0.70	0.66	...	0.37	...	...	...	150
.....	...	...	...	...	...	...	...	...
.....	0.79	0.69	...	...	...	...	...	143
.....	0.86	0.68	...	0.35	...	...	...	86
19,000	0.77	0.65	0.50	0.42	0.21	0.28	0.31	130
‡16,300	...	0.74	...	0.42	0.21	...	...	109
.....	0.74	0.70	...	0.33	...	...	...	150
12,000	0.88	0.72	0.46	0.33	0.16	0.18	0.22	93
.....	0.80	0.72	...	0.43	...	...	...	124
.....	0.88	0.67	...	0.43	...	...	...	109
.....	0.91	0.73	...	0.40	...	...	...	83
.....	0.93	0.76	...	0.38	...	...	...	83
.....	0.63	0.58	...	0.42	...	...	...	159
.....	0.80	0.72	...	0.40	...	...	...	86
14,500	0.94	0.70	0.43	0.49	0.21	0.22	0.29	100
17,000	0.86	0.72	0.49	0.49	0.24	0.28	0.34	89
.....	0.55	0.58	...	0.38	...	...	...	143
.....	0.82	0.73	...	0.38	...	...	...	80
13,000	0.79	0.67	0.56	0.40	0.22	0.28	0.33	89
13,000	0.86	0.70	0.62	0.40	0.25	0.29	0.36	70
.....	0.84	0.71	...	0.36	...	...	...	86
.....	0.98	0.75	...	0.36	...	...	...	61
6,000	0.84	0.64	...	...	0.15	0.18	0.24	70
.....	0.77	0.67	0.48	0.31	...	...	...	74
.....	...	0.68	...	0.31	...	...	...	45
4,000	0.95	0.76	0.42	...	0.13	0.13	0.17	41

been annealed by the manufacturers at 550° F. ‡AW was AW-1 as received in Parts I and II. as AW-2 annealed in Parts I and II. §Was material BH-1 in Part I. ‖Was material BH-2 in

strength to shearing strength were plotted, it would be similar in form to the upper two curves of this figure.

Fig. 11 represents results obtained with other nickel-copper alloys as well as with nickel. The upper curve indicates that for all these alloys cold working up to an index to about 40 per cent increases the rotating-cantilever endurance limit in proportion to the increase in tensile strength. Results for severely cold-worked material have been obtained only with nickel.

The lower graph of Fig. 11 is similar to the lowest graph of Fig 10. It seems to indicate that there is some relationship between the ratio of shearing strength to tensile strength and the rotating-cantilever endurance limit. In both graphs of Fig. 11, and in the lowest and upper two graphs of Fig. 10, there is a rather abrupt approach to a horizontal direction at a point corresponding to a cold working index of about 40 to 60 per cent. Additional experiments on the effect of degree of cold working on the ratio of shearing strength to tensile strength are being made. In the meantime, discussion of the significance of the rather abrupt changes in direction of the two curves in Fig. 11 could be only tentative.

A distinction should be made between the grain distorting effects and the grain refining effects of cold working. When the final cold working stage has been preceded by a series of stages of cold working and annealing, there may be considerable grain refinement in addition to the final grain distortion. That grain refinement may produce increase in tensile strength without decrease of endurance ratio is indicated by the results of endurance tests on nickel, materials A-11 and CT-10, that had been annealed at about the temperature of incipient recrystallization. Metallographic examination of materials A and CT as received, however, would indicate that the cold working process has produced little if any grain refinement. The cold working index used in Figs. 10 and 11, therefore, as applied to these materials probably represents chiefly the grain distorting effects of cold working.

Effect of Cold Working and Annealing on Alternating-Torsion Endurance Properties

Only a few results have been obtained in an investigation of the effect of cold working and annealing on alternating-torsion en-

durance properties. The results are given in Fig. 15. The upper two graphs of this figure show results obtained with severely cold-worked nickel, material A. The graph for material "as received"

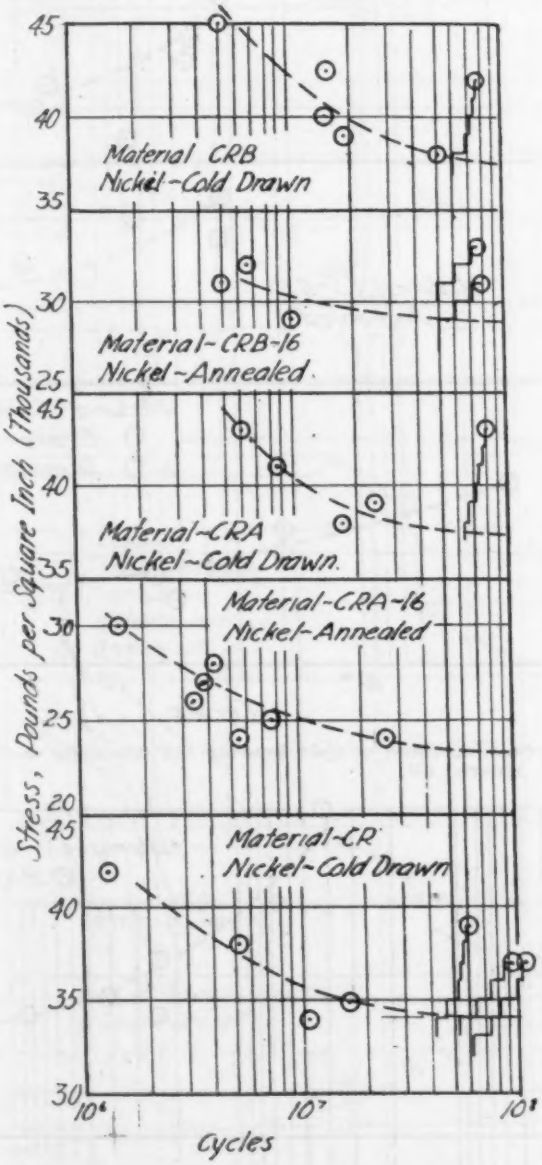


Fig. 2—Graphs Showing Effect of Cold Drawing and Annealing on the Endurance Properties of Nickel, Materials CRB, CRA and CR

was obtained with short specimens. The lower end of this graph, therefore, has probably not descended quite to the "endurance limit" of this material. The graph for annealed material, A-16, is an "accelerated fatigue" graph; the lower end, therefore, is probably at the "endurance limit." A comparison of these two

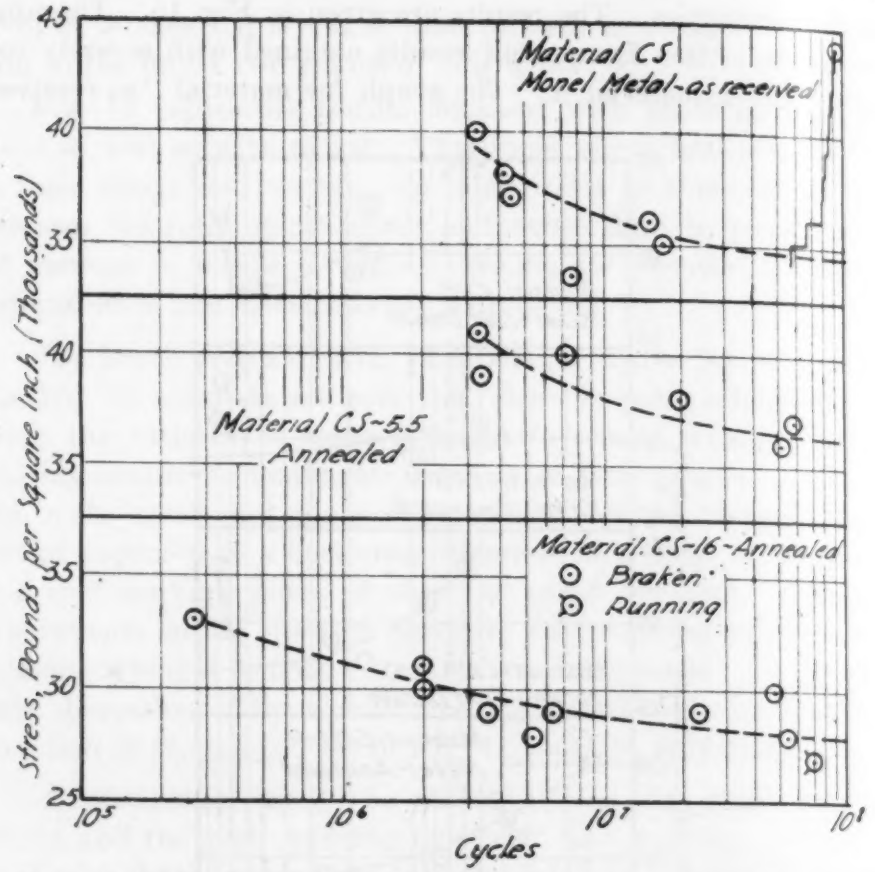


Fig. 3—Graphs Showing Effect of Cold Drawing and Annealing on the Endurance Properties of Monel Metal, Material CS.

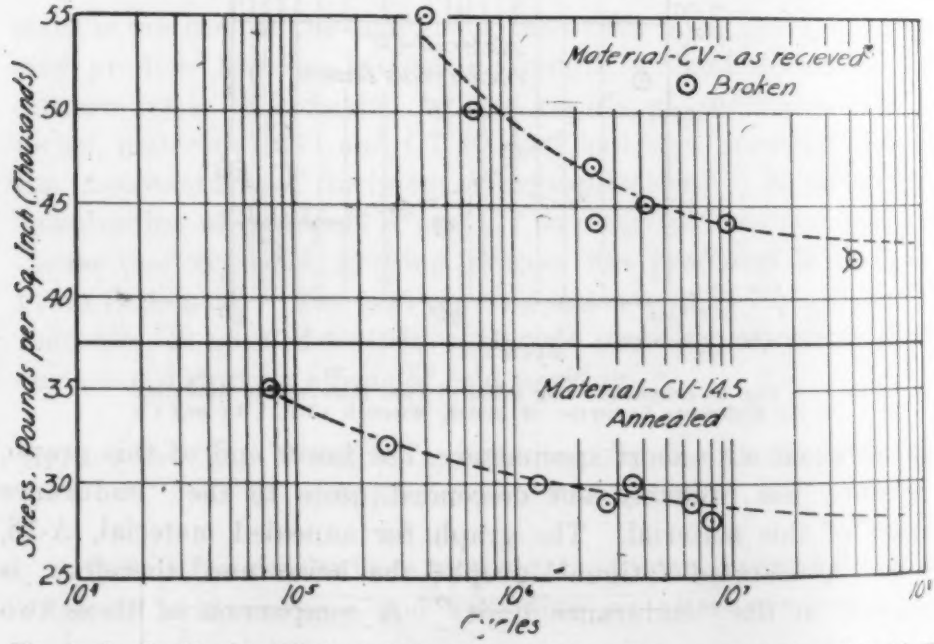


Fig. 4—Graphs Showing Effect of Cold Rolling and Annealing on Constantan, Material CV.

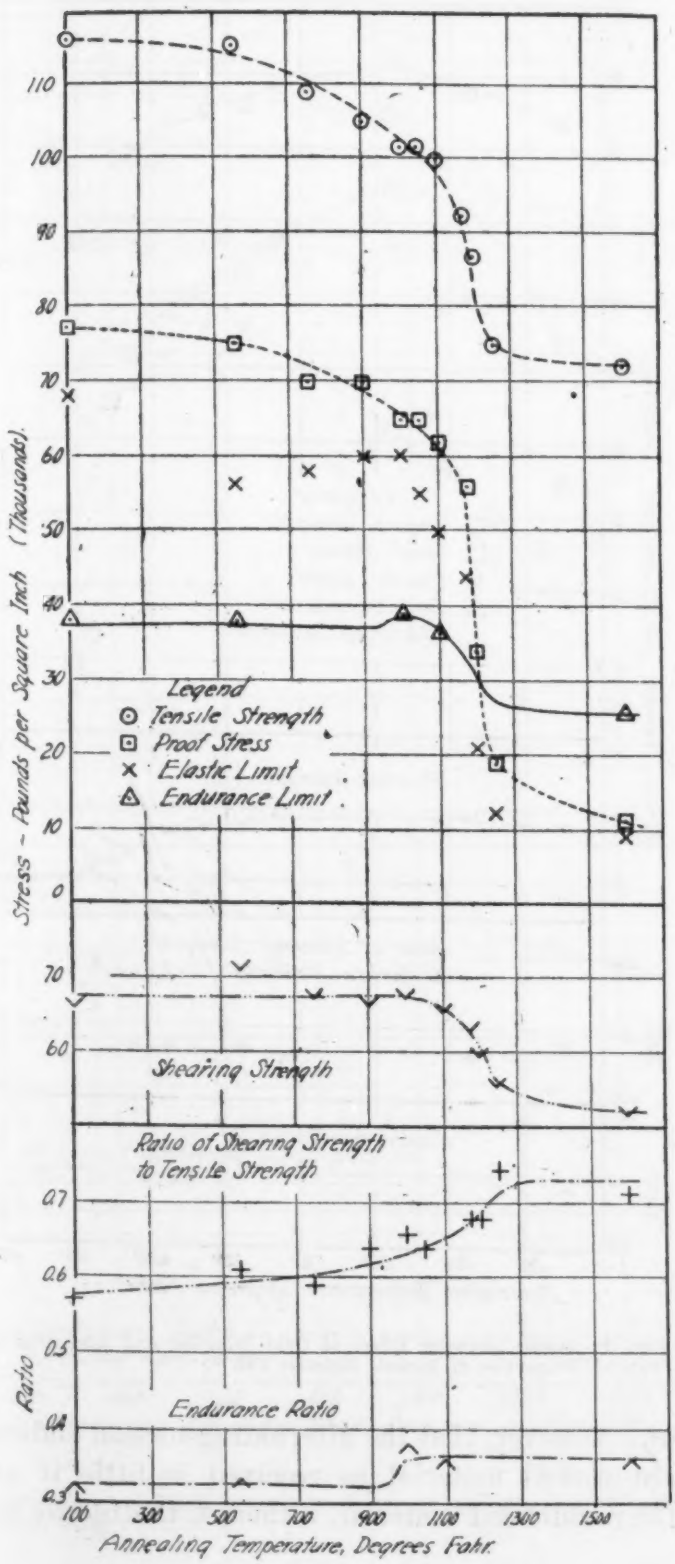


Fig. 5—Graphs Showing Effect of Cold Working and Annealing on the Physical Properties of Nickel, Material CT.

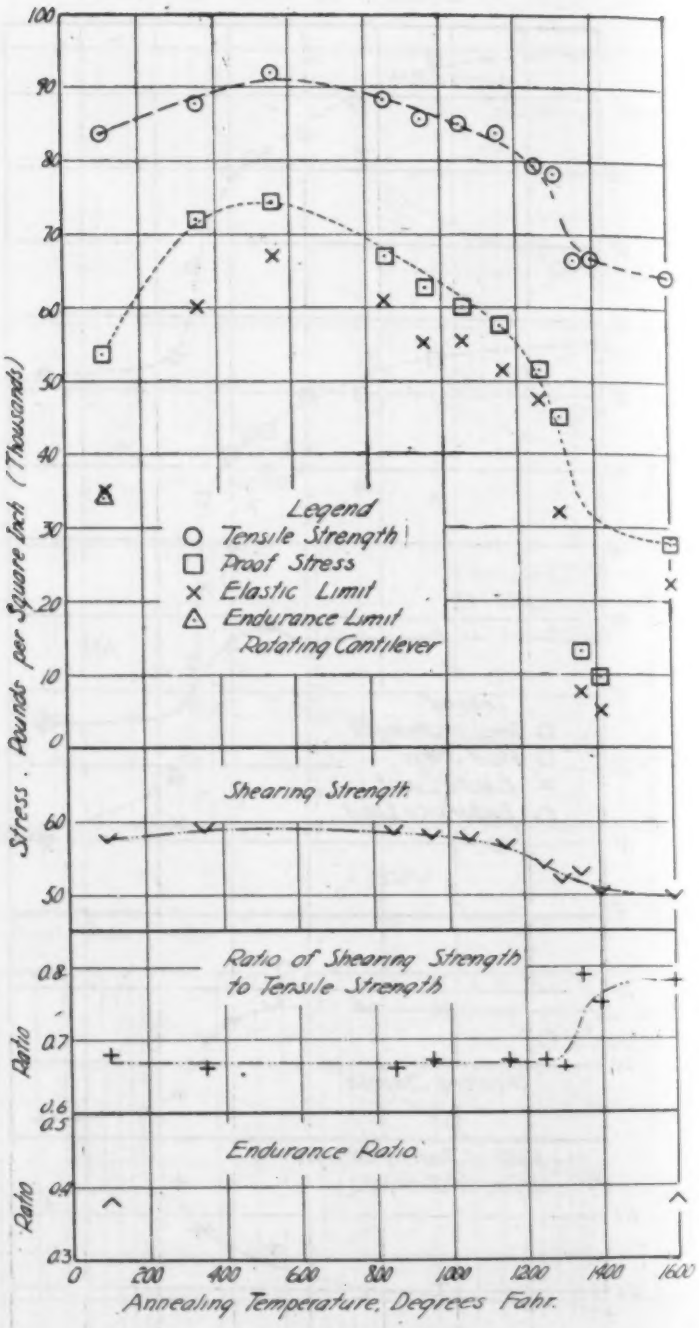


Fig. 6—Graphs Showing Effect of Cold Working and Annealing on the Physical Properties of Nickel, Material CR.

graphs shows, however, that the alternating-torsion endurance limit for the cold-worked material as received is little if any higher than for fully annealed material, although the tensile strength of

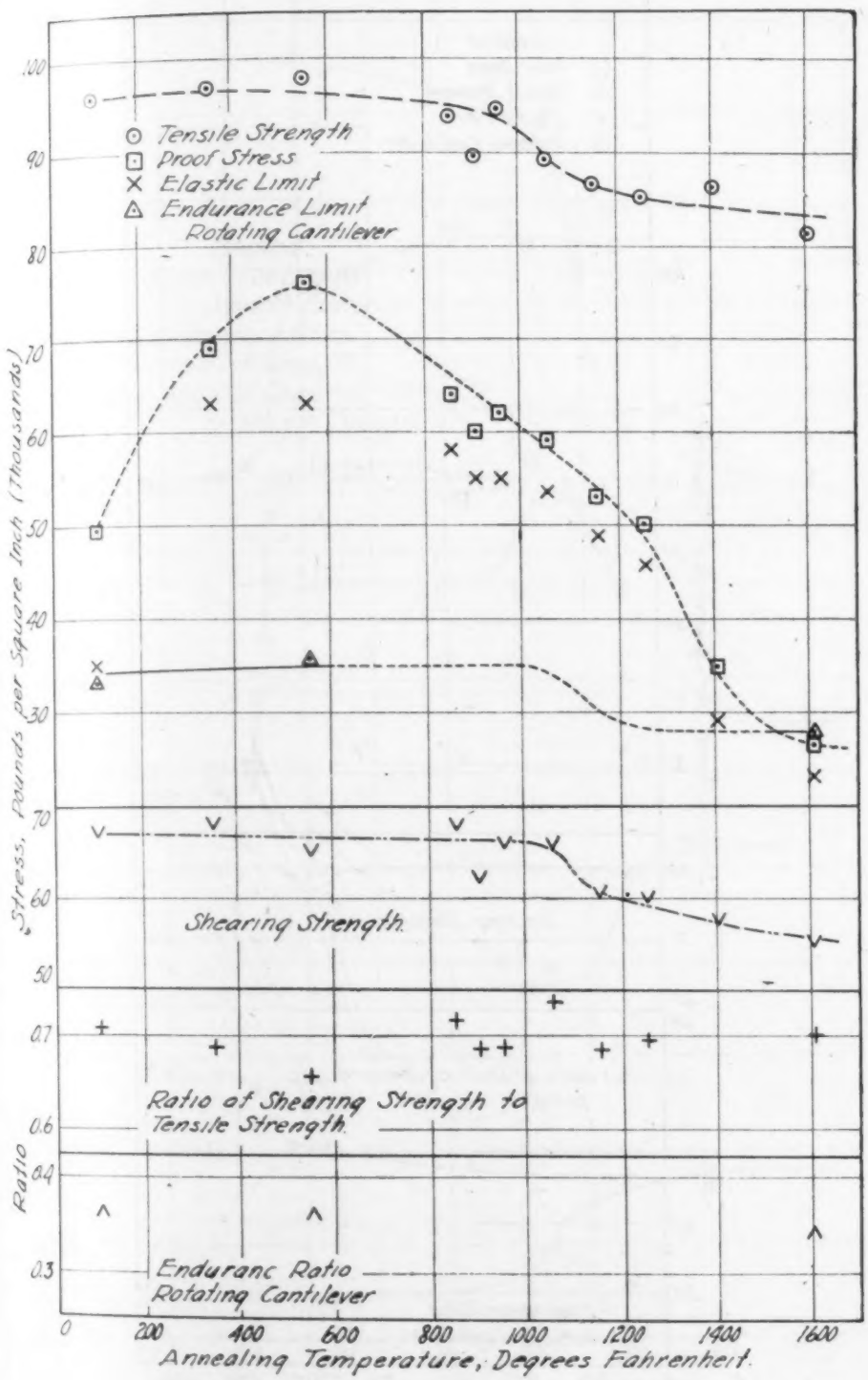


Fig. 7—Graphs Showing Effect of Cold Working and Annealing on the Physical Properties of Monel Metal, Material CS.

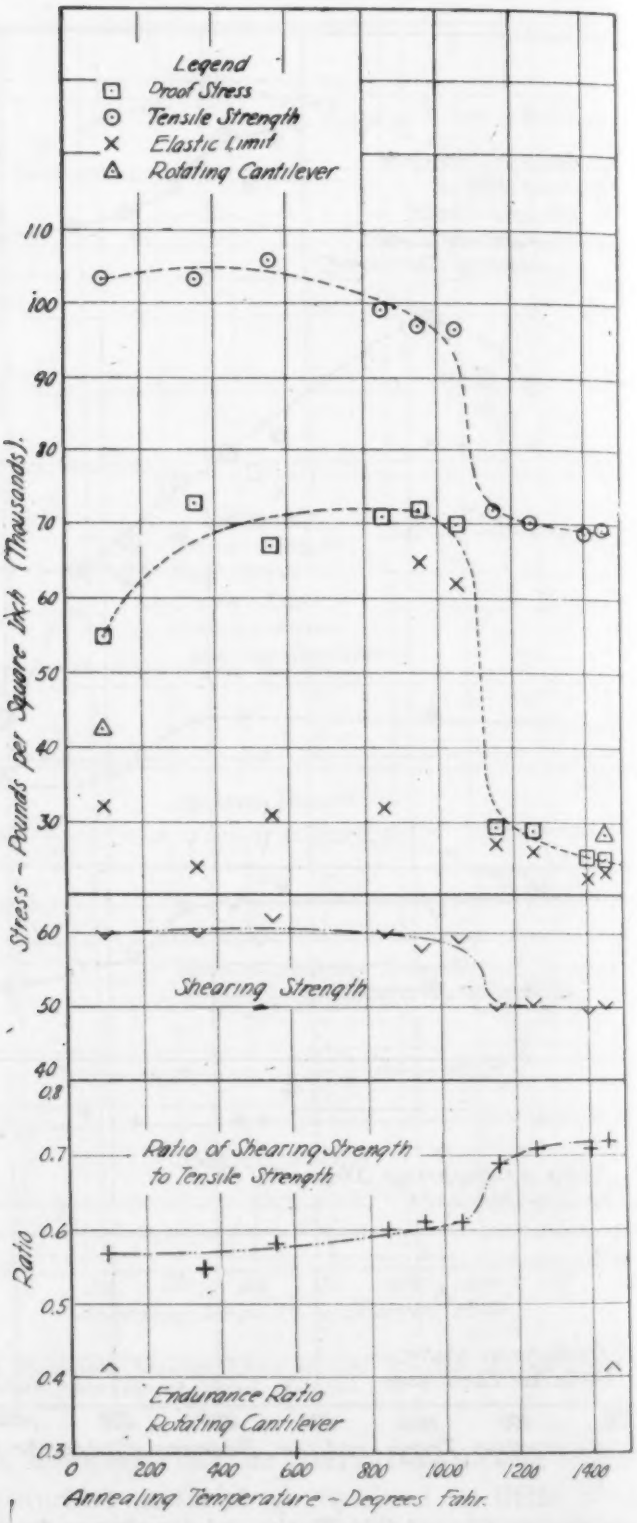


Fig. 8—Graphs Showing Effect of Cold Working and Annealing on the Physical Properties of Constantan, Material CV.

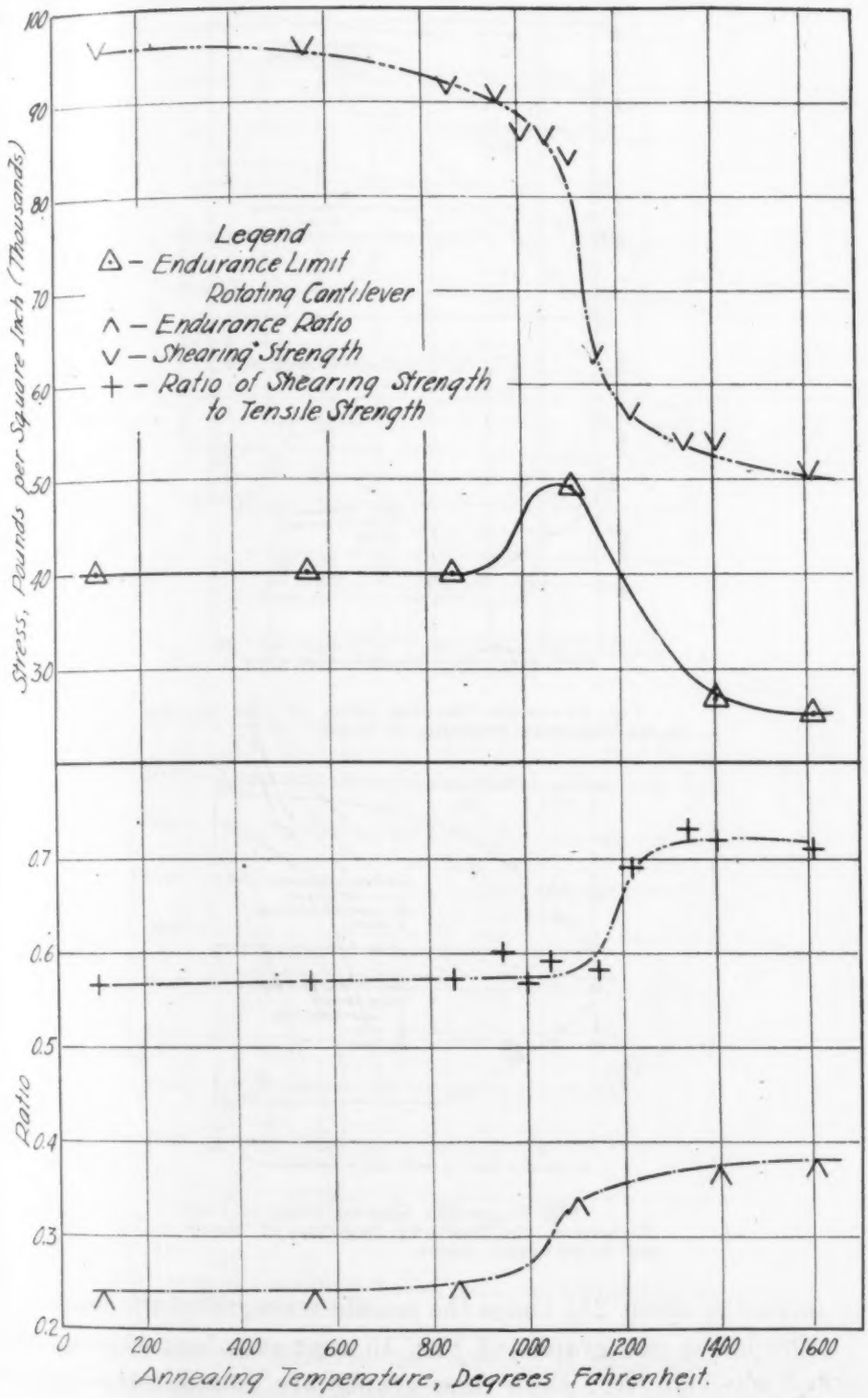


Fig. 9—Graphs Showing Effect of Cold Working and Annealing on the Physical Properties of Nickel, Material A.

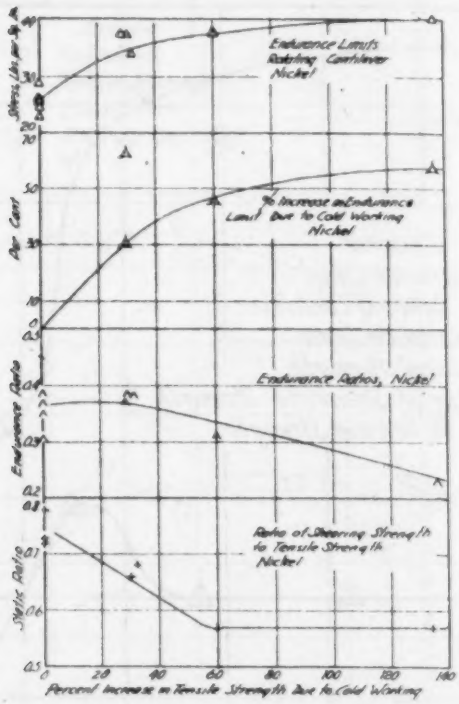

Endurance Limits Rotating Cantilever Nickel
% Increase in Endurance Limit Due to Cold Working Nickel
Endurance Ratios, Nickel
Ratio of Shearing Strength to Tensile Strength Nickel
Per Cent
Static Ratio
Percent Increase in Tensile Strength Due to Cold Working

Fig. 10—Graphs Showing Effect of Cold Working on the Endurance Properties of Nickel.

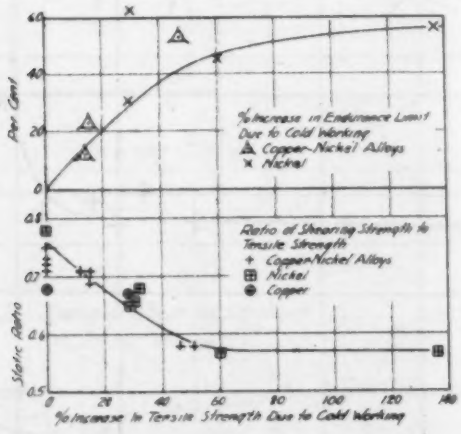


Fig. 11—Graphs Showing Effect of Cold Working on the Endurance Properties of Nickel and Nickel-Copper Alloys.

the former is about 2⅓ times the tensile strength of the latter.

The lower two graphs of Fig. 15 represent less severely cold-worked material CT. Both these graphs are "accelerated-fatigue" graphs. The broken line graphs as drawn, therefore, probably point to the "endurance limits." It will be observed that the en-

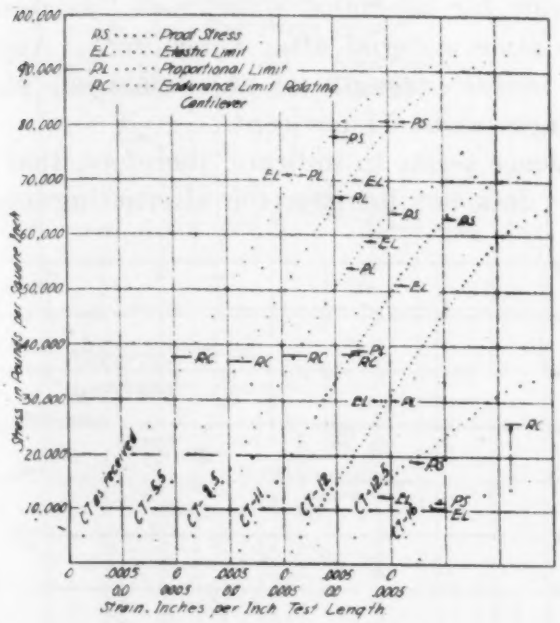


Fig. 12—Results of Tension Tests, Stress-Strain Graphs, Cold-Rolled Nickel, Material CT.

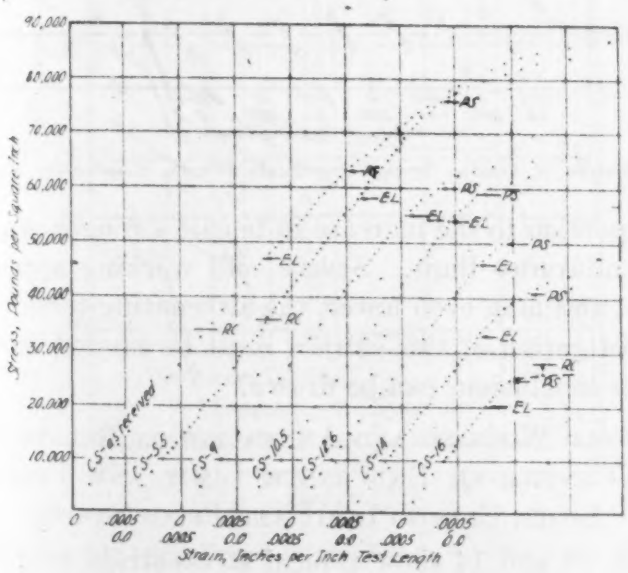


Fig. 13—Results of Tension Tests, Stress-Strain Graphs, Monel Metal, Material CS.

durance limit for the material as received is somewhat lower than for fully annealed material, although the tensile strength of the former is about 1.6 times the tensile strength of the latter.

A reference to Fig. 18 will show that the alternating-torsion

endurance limit for hot-rolled constantan "as received" is lower than for the same material after annealing. Annealing did not change the tensile strength of this material, but lowered the Brinell hardness about 11 per cent.

The evidence seems to indicate, therefore, that even moderate cold working does not increase the alternating-torsion endurance

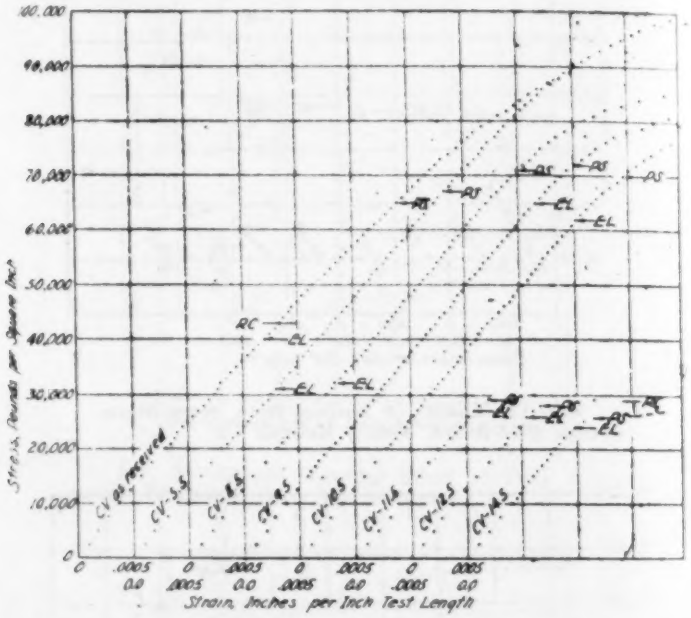


Fig. 14—Results of Tension Tests, Stress-Strain Graphs, Constantan, Material CV.

limit in proportion to the increase in tensile strength, and may even lower this endurance limit. Severe cold working apparently does not increase, and may even lower, the alternating-torsion endurance limit. Investigation of this subject must be carried further before more definite conclusions can be drawn.

Effect of Cold Working and Annealing on Relation Between Rotating-Cantilever Endurance Limit and Proportional Limit, Elastic Limit and Proof Stress

Figs. 12, 13 and 14 show typical stress-strain graphs for cold-worked nickel, monel metal, and constantan. The graphs were obtained by means of extensometer readings in ordinary tension tests. In each figure is a series of graphs representing the effect of temperature of anneal on the form of the stress-strain graph. The first graph in each figure represents material as received. The other graphs in order from left to right illustrate the effect of in-

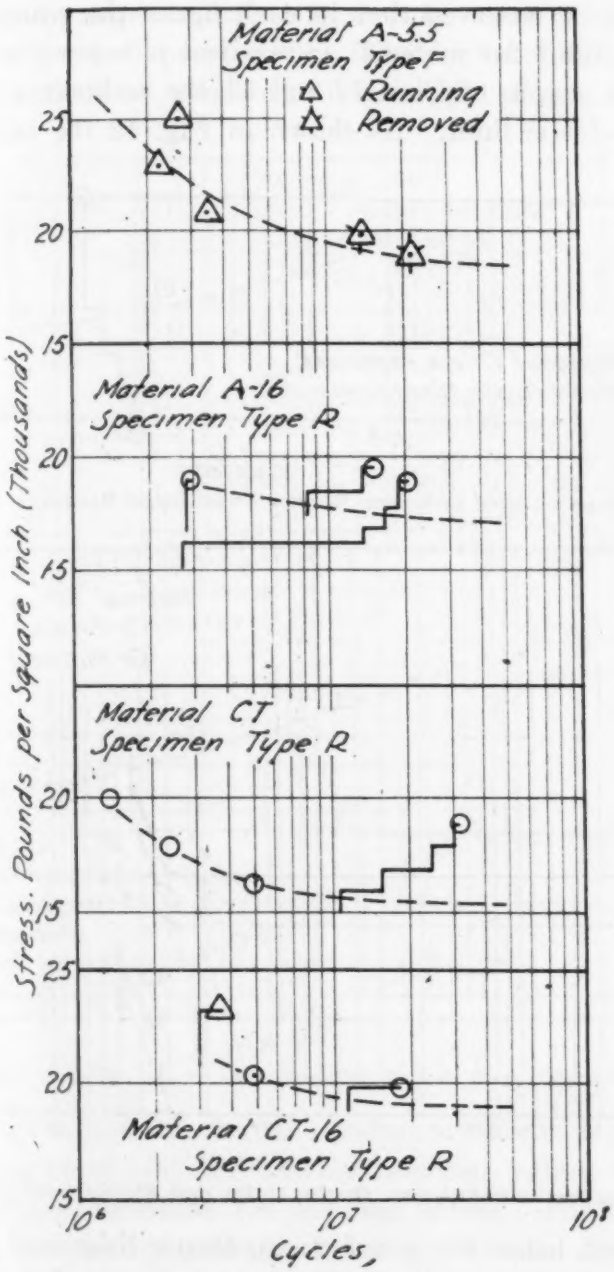


Fig. 15—Alternating Torsion Graphs, Nickel, Materials A and CT.

creasing temperature of anneal. On each graph, the position of the proportional limit, elastic limit, and proof stress has been marked. The rotating-cantilever endurance limit, whenever it is available, has also been marked on each graph with the proper ordinate.

It will be observed that in each figure the rotating-cantilever endurance limit for material as received is below the proof stress. In the first graphs of Figs. 12 and 13, the endurance limit is much below the elastic limit. As shown in Fig. 12 the endurance limit

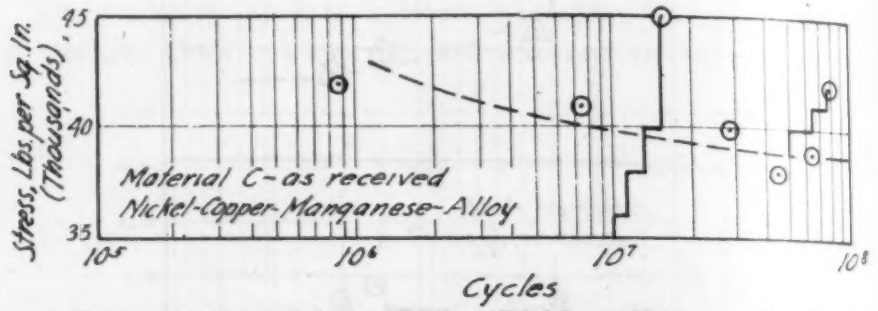


Fig. 16—Rotating-Cantilever Endurance Results, Nickel-Copper-Manganese Alloy, Material C.

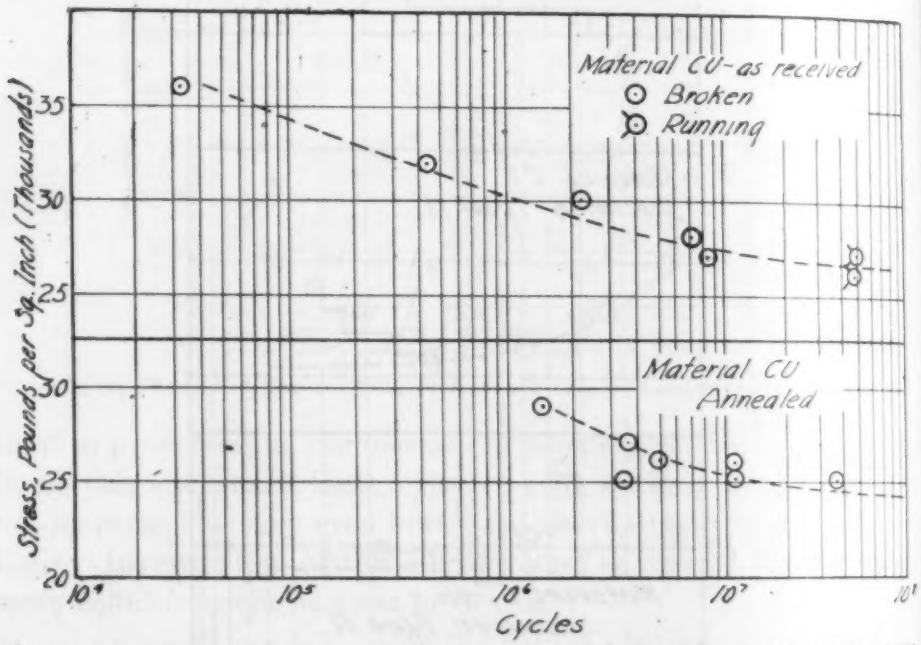


Fig. 17—Rotating-Cantilever Endurance Graphs, 55 Per Cent Nickel-Copper Alloy, Material CU.

remains much below the proof stress, elastic limit and proportional limit until the temperature of anneal has exceeded 1100 degrees Fahr. near the beginning of the recrystallization range. As shown in Figs. 13 and 14, for fully annealed material the endurance limit is above the proof stress, and apparently above the yield point of the material.

This change in the relationship of endurance limit to proof stress caused by annealing cold-worked material is evident in Figs.

5 to 8 inclusive. In nearly all those figures the curve of endurance limits crosses the curve of proof stress. The degree of deformation at the endurance limit of annealed nickel-copper alloys is appar-

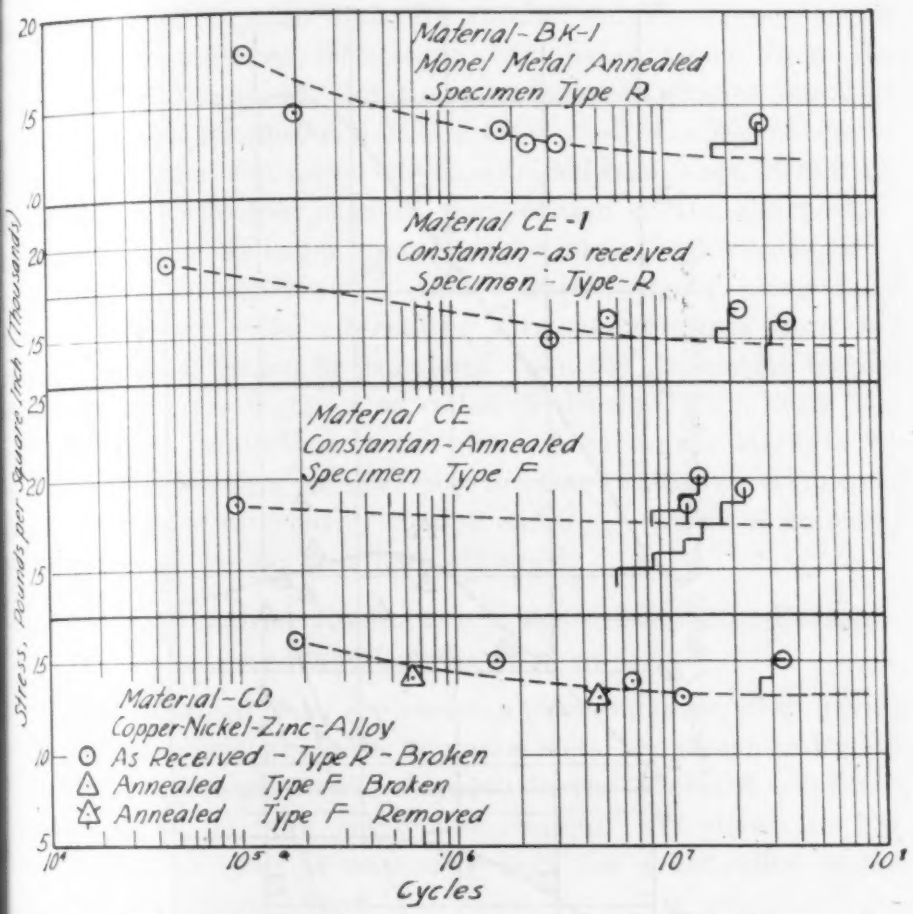


Fig. 18—Graphs Showing Results of Alternating Torsion Tests, Nickel-Copper Alloys.

ently so great as to indicate that the endurance limits as calculated from a rotating-bend test are merely nominal values calculated from the ordinary formulas for bending stress. The actual endurance limit stresses are probably lower sometimes. Nevertheless the endurance limits as determined by a rotating-bend test are of great value in design of machinery parts.

Effect of Chemical Composition on Endurance Properties of Nickel-Copper Alloys

Additional Data

In Fig. 5 of Part II tentative graphs were drawn to represent

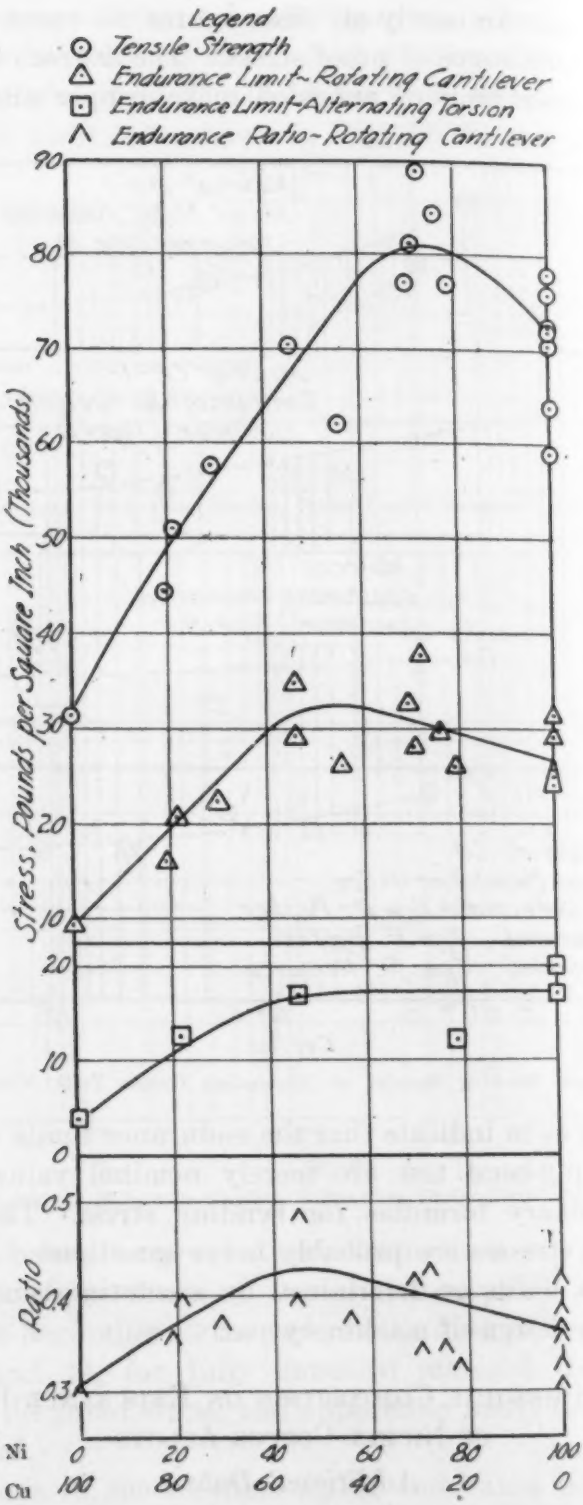


Fig. 19—Graphs Showing Effect of Composition on the Physical Properties of Annealed Nickel-Copper Alloys.

the effect of chemical composition on rotating-cantilever endurance properties. Since the publication of those graphs, additional rotating-cantilever endurance limits of nickel-copper alloys have been obtained. Endurance limits for another sample of monel metal and another sample of constantan can be obtained from the graphs of Figs. 3 and 4. Rotating-cantilever endurance limits of a hot-rolled nickel-copper-manganese alloy and of a nickel-copper alloy having 55 per cent nickel can be obtained from Figs. 16 and 17. To estimate the effect of chemical composition on the alternating-torsion endurance limit for nickel-copper alloys it is necessary to make actual determinations of this endurance limit using fully annealed material. The alternating torsion endurance limit for annealed material cannot be calculated from the alternating-torsion endurance limit for material as rolled or drawn. This limit does not increase in proportion to the increase in tensile strength by moderate cold working as does the rotating-cantilever endurance limit. A series of alternating-torsion endurance limits of annealed nickel-copper alloys has now been obtained.

Rotating-Cantilever Results for Additional Hot-Rolled Nickel-Copper Alloys

Results obtained with a nickel-copper-manganese alloy having a composition somewhat similar to monel metal are shown in Fig 16. This alloy has a high tensile strength in the annealed condition, possibly due to its high manganese content. As shown in Fig. 16 its endurance limit is unusually high for a hot-rolled nickel-copper alloy.

Fig. 16 shows results obtained with a hot-rolled alloy containing 55 per cent nickel. The tensile strength and endurance ratio of this alloy are lower than was expected for an alloy of this composition. As shown in Table I, the percentages of iron, manganese, and carbon are lower in this alloy than in any other nickel-copper alloy listed in Table I, except the alloys of relatively low nickel content. This may account for the unexpectedly low tensile strength and endurance limit of this alloy.

Results of Alternating-Torsion Tests on Some Nickel-Copper Alloys

Results of alternating-torsion tests on some nickel-copper alloys are shown in Fig. 18. With two exceptions these tests were made

by the accelerated-fatigue method described in Part I. It will be noted that these graphs apparently reach a nearly horizontal direction at fewer cycles than do the rotating-cantilever graphs of such material.

As shown in Fig. 18 annealed constantan has a higher endurance limit than hot-rolled constantan. As shown in the lower graph annealing the hot-rolled copper-nickel-zinc alloy has little if any effect on the endurance limit.

Graphs Showing Effect of Chemical Composition on Endurance Ppoperties of Nickel-Copper Alloys

With the additional data now available it is possible to supplement the graphs shown in Fig. 5 of Part II, illustrating the effect of chemical composition on endurance properties. Instead of estimating the effect on the equivalent composition of small percentages of elements other than nickel and copper according to Guillet's "coefficients of equivalence" as was done for Fig. 5 of Part II, the actual percentages of nickel and copper in each alloy have been recalculated on the assumption that the alloy is made up entirely of nickel and copper in the proportions actually present. This has the effect of considering the other elements as being distributed to the nickel and copper in proportion to the percentages of nickel and copper present. This method seems preferable to the Guillet method for representing the alloys as equivalent binary alloys, especially when the curves are nearly horizontal as they are on the right sides of Fig. 5 of Part II and of Fig. 19 of the present paper. The newer method of representation of equivalent binary alloys has been used in Fig. 19. To apply corrections to these graphs for the effects of manganese, iron and nickel, it would be necessary to decrease the ordinates to some extent. No definite information is now available for quantitative correction in this way. In Fig. 19 the new points for rotating-cantilever endurance limit and endurance ratio have made it necessary to make the downward slope of the corresponding curves to the right less than in Fig. 15 of Part II. The highest point in each of these two curves, however, is still apparently at a point representing an alloy containing about 45 to 55 per cent nickel.

The highest point on the curve of tensile strength is at a point representing monel metal composition. It should be noted, how-

ever, that the alloys of this composition contain much more manganese and iron than the alloys having lower percentages of nickel.

The comparatively few points for alternating-torsion endurance limit seem to indicate that the curve should be nearly horizontal as drawn between the abscissas representing 45 and 100 per cent nickel. Additional experiments are being made to supplement this graph.

Acknowledgement is hereby made of the encouragement in this work received from Captain P. B. Dungan, U. S. N., Officer in Charge, U. S. Naval Engineering Experiment Station and of the assistance received from G. F. Wohlgemuth and L. Thompson, associate metallurgists and from J. L. Basil and A. P. Vandermast, laboratorians at the Naval Experiment Station.

RESOLVING POWER, MAGNIFICATION, AND ENLARGEMENT

By W. M. Mitchell

Abstract

This paper describes in a theoretical way the considerations affecting the resolving power of the microscope. It includes a description of Abbe's theory of microscopic vision, and explains the importance of "numerical aperture," as introduced by Abbe.

The maximum theoretical resolving power of the microscope is calculated for visual observations and for photomicrography, for both dry and immersion objective systems. From these are determined the magnification necessary to show full detail resolved by the objective when used visually or photographically.

A discussion is given of the resolving power of the photographic plate as determined by the size of the silver grains in the emulsion. The use of enlargement to obtain large photographs at high magnification from small negatives, with the advantages offered by such photographs, is explained.

IN view of the increasing application of high power photomicrography to studies of metallic structures it is desirable to investigate some of the peculiarities of the optical system of the microscope, especially what may be seen by it under conditions of highest magnification, what its limitations are in such use, with the causes of such limitations.

In order that there may be no misunderstanding regarding the use of technical terms, and for the purpose of what follows, such terms will be understood to be defined as follows:

Object—The surface of the specimen examined with the microscope.

Image—The optical counterpart or picture of the object formed by a lens; which may be real, as when it is projected or received on a screen, or virtual, when it is not capable of being so projected. What may be called the "ultimate image" is the reproduction of the object seen by the eye through the eyepiece, or projected upon the focusing screen.

The author, Dr. Walter M. Mitchell, member A. S. S. T., is metallurgist with E. I. duPont de Nemours and Co., Wilmington, Delaware.

Resolving Power—The ability of an optical instrument, such as a microscope, to "resolve" or separate the finest details of the object so that they are distinctly visible to the eye. Resolving power is usually measured by the maximum number of lines per millimeter (or inch) which may be distinctly separated by the instrument.

Magnifying Power or Magnification—The ratio of the apparent linear dimensions of the ultimate image as seen by the eye to the actual linear dimensions of the object. Thus, if a detail of the structure of the object is $^1/_{100}$ of a millimeter in diameter, and appears in the microscope to be the same size as an object one millimeter in diameter seen at the normal distance of distinct vision (25 centimeters) we say that the magnification is 100 diameters, or 100 times = 100×.

Enlargement—Enlargement is magnification of the ultimate image,—such as a magnified photographic reproduction of an original negative; the degree of enlargement being the ratio of the linear dimensions of the enlargement to the original negative. Obviously enlargement can reveal no other detail than is in the negative itself.

The arrangement of the optical system of the microscope is shown in Fig. 1. P_1P_2 is the object, O the objective forming an image of the object which would normally fall on the plane H; but owing to the field lens E of the eyepiece, the rays of light converge more rapidly and form the real inverted image $P_1'P_2'$. A field of view stop is placed at this position which sharply limits the field of view. The eyelens E′ of the eyepiece magnifies the image $P_1'P_2'$, producing the inverted virtual image $P_1''P_2''$, which is the ultimate image seen by the observer at K. The arrangement is usually such that this image is at the normal distance of distinct vision. In the inverted type of microscope a totally reflecting prism is placed between the objective and the eyepiece, which changes the direction of the path of the rays, but in no way affects the formation of the images.

The theory of the resolving power of the microscope, in contrast to the geometrical theory of image formation, is somewhat complicated and probably is still incompletely solved. Early investigators, notably Airy and Helmholtz, assumed that the microscope image was formed in the same manner as the image in

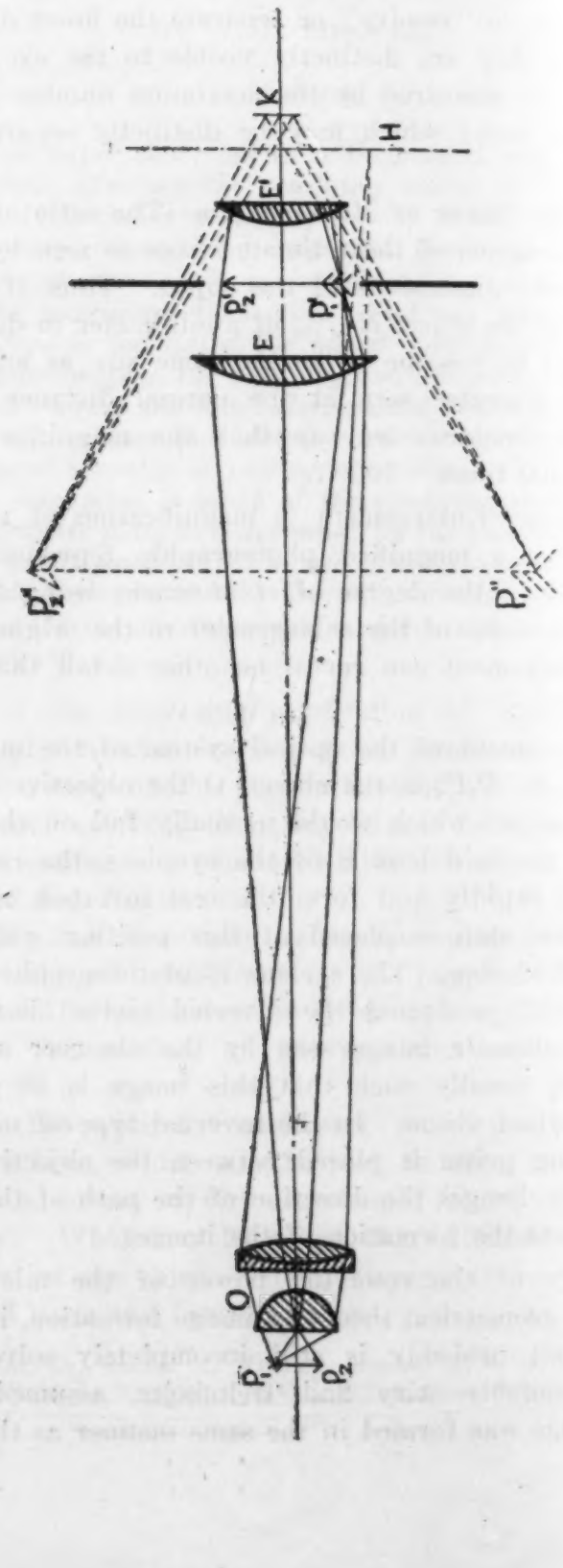


Fig. 1—Arrangement of the Optical System of a Compound Microscope.

the astronomical telescope and worked out a theory of microscopic imagery accordingly. However, the telescope is chiefly used on stars, which are self-luminous bodies, sending out coherent light waves, which Airy correctly considered as determining the formation of the image. This fact was overlooked by the early investigators of the microscope who did not realize that the object observed either transmits or reflects the light which is projected on it and which produces effects of an entirely different nature.

The modern theory of microscopic vision was introduced by Ernst Abbe, who showed the incorrectness of the earlier theories, and demonstrated that the formation of the image by the microscope objective is due to the interference of pencils of rays of light from an outside source which suffer diffraction because of the structure of the object; the resolving power being dependent upon the extent to which these diffracted rays are admitted by the aperture of the objective. While Abbe's theory has not been without opponents, it has survived all attacks and now after fifty years is the accepted theory of microscopic vision.

Abbe showed that resolving power was limited by the nature of light itself; i. e., the phenomena of interference and diffraction. From the standpoint of purely geometrical optics, which deals with light rays as mathematical directions, the similarity of image and object follows from principles which have been well established. But from the standpoint of physical optics, which does not deal with rays of light as independent geometrical directions, since this is not rigorously permissible, but which is based on deformations of the wave front, the similarity of object and image is not only not self-evident but is, strictly speaking, actually unattainable.

Abbe showed that the images of minute objects—those comcomparable with the wave-length of light—depend entirely upon the effect of diffraction, and involve a characteristic change which fine structural details of the object effect in transmitted (or reflected) light in proportion to their minuteness. The change consisting in the breaking up of the illuminating incident beam of light into bundles or groups of rays which are spread out fan-like at considerable angular distance from the path of the normal transmitted (or reflected) ray, and within the range of which occur periodic variations of light and dark. Each bundle of

diffracted rays thus consists of a central or direct beam which is surrounded on each side by fainter beams of light, or spectra, these diminishing in intensity as the angular distance from the central beam increases. If properly projected on a screen, such an assemblage of spectra form what is called a "diffraction pattern." In consequence of this the task of the optician is to construct a microscope objective which will admit as much as possible of this diffraction pattern.

With objects of relatively coarse structure the diffracted rays are confined within a very narrow angular space around the central ray, and will, therefore, not appear separated from it except with long focus objectives. The whole of the diffracted bundle of rays is, consequently, admitted into the objective, and in such cases the image is strictly similar to the object.

If, on the contrary, the structure is fine, the angular dimensions of the bundle of diffracted rays increases in accordance with the well known expression:

$$\sin \Phi = \frac{m\lambda}{b}$$

Where Φ is the angle of diffraction of one of the side beams, or spectra, whose "order" or number from the central beam is m, and b is the dimensions of the structure of the object; the light being incident normally. From which it is seen that as b decreases (the smaller the structure) Φ increases, so that the rays are more spread out from the central beam. In such cases, depending upon the greater or less aperture of the objective, more or less of the diffracted bundles of rays may not be admitted by it.

The formation of the image by the microscope objective is explained by the fact that the rays collected at its back, depicting there the direct and spectral images of the source of light, reach in their further course the plane which is conjugate to the object and there give rise to an interference phenomenon which produces the image magnified by the eyepiece. If the whole bundle of rays is not admitted the image must needs be incomplete; i. e., defective, and not an exact reproduction of the object itself. Thus, the perfection of the microscope image depends essentially upon the number and distribution of the diffracted bundles of light which enter the objective.

Experiments[1] show the correctness of the above statements. Objects with dissimilar structures will give identical microscopic images when the difference of their diffractive effects are removed; and, conversely, similar structures will give dissimilar images when their diffractive effects are made dissimilar.[2] Abbe further found that by stopping out the diffracted spectra one after the other until at last none were admitted, the definition and resolution fell off more and more and the image finally ceased entirely to represent the object.

Minute structural details as imaged by the microscope, are not to be strictly interpreted as images of material forms, but only as signs of material differences of composition of the particles composing the object; so that nothing can be safely inferred from the image as presented to the eye *other than the presence in the object of such structural peculiarities as will produce that specific diffraction phenomenon on which the formation of the image depends.*

In consequence of the manner of image formation in the microscope it follows that:

1. If the structure of the object is so fine, or the lens aperture so small, that no part of the diffracted bundles can enter the objective, no structure will be revealed, no matter what the magnification. The field of the microscope will show simply uniform illumination.

2. In order to bring out any structure the aperture of the objective must be so great that not only the effect of the direct beam of the diffracted bundle appears, but also that of at least one of the side spectra. Under such conditions some sort of image appears which has a rough similarity to the object.

3. As more of the side spectra are admitted by the objective the image becomes more and more similar to the object, but will differ from an exact representation of it, and will correspond to that of some other object whose entire (effective) diffraction pattern is identical with that portion which can enter the lens.

4. Perfect similarity is to be attained only when all the bundles diffracted by the object, which are of sufficient intensity to produce an appreciable effect at the focal plane of the objective, take place in the formation of the image.

[1] Carpenter, The Microscope and its Revelations, Phila., 1901, p. 67.

[2] See Porter, Philosophical Magazine, 1904 and 1906.

This shows the great importance of using objectives of large aperture; that is, numerical aperture (which is to be described presently), in order to reproduce as closely as possible the exact structure of the object. Perfect similarity is an impossibility, even theoretically,—the microscope reproduces the details of the object up to a certain limit only.

The resolving power determines the fineness of the details of the object that are reproduced in the image; in exact form,—the

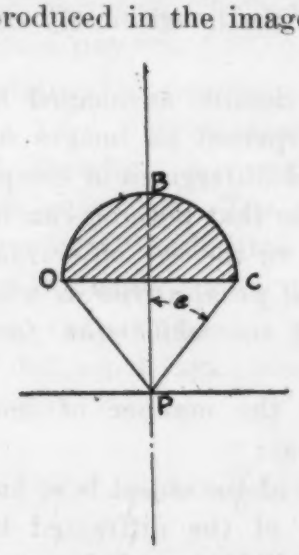


Fig. 2—Diagrammatic Sketch Depicting What is Meant by Numerical Aperative.

distance apart d of two neighboring points P_1 and P_2 which can just be separated. This, as we have seen, is dependent upon the aperture, or, rather, ray gathering power of the objective. Abbe has shown that aperture does not mean merely the size of the opening in the cell containing the lenses, but depends also upon the working distance of the objective from the object. He has thus introduced a quantity called the numerical aperture which may be defined as follows:

Let OBC, Fig. 2, represent the first lens of the objective, P a point of the object, e the angle made with the optical axis BP by the ray PC which just passes the rim of the objective; equal to the semi-angle of the cone of rays which just fills the objective. Let n = the index of refraction of the medium between P and OC. Then the quantity called numerical aperture by Abbe is given by the expression:

$$\text{N. A.} = n \sin e. \qquad (1)$$

from which it will be seen that numerical aperture depends upon the medium traversed by the rays of light, and the relative dimensions, through e, of the lens aperture and its working distance. Actually it is equal to the ratio of the semi-diameter of the back lens of the objective to the focal length of the objective system.

What fineness of structure will be revealed depends upon its configuration and character. Perhaps the simplest case to consider is that of fine dark lines, such as the laminated structure of pearlite, lines separated by spaces approximately equal to their width. If d is the distance apart (center to center) of two such lines L_1 and L_2, in order to be just resolved by the objective under the most favorable conditions of illumination, we must have, according to the theory of Abbe:[3]

$$P \geq \frac{\lambda}{2\,N.A.} \qquad (2)$$

in which λ = the normal wave-length of the light employed.

If we put R equal to the resolving power, then from the original definition, we have:

$$R = \frac{1}{d} \qquad (3)$$

and whence:

$$R = \frac{2\,N.A.}{\lambda} \qquad (4)$$

which expression shows that resolving power varies directly as the numerical aperture, and inversely as the wave-length of the light employed; and, therefore, may be increased only by increasing the former, or diminishing the latter, or by both.

From (1) it is evident that increase of n increases numerical aperture. For air, $n = 1$, but by introducing a medium for which $n > 1$ between the object and the objective, numerical aperture may be increased proportionately. The medium usually employed is oil of cedar, for which $n = 1.52$. An objective used under such a condition is known as an immersion system, and has the further advantage that, through the greater refracting power of the medium, the diffracted bundles of light from the object are refracted toward the optical axis so that more of the diffraction pattern becomes available for improvement of the image.

With dry immersion, that is, air, the practical limit of

[3] Drude, Lehrbuch der Optik, p. 221.

numerical aperture is 0.95 and it is obvious that this cannot be exceeded because n = 1, and e can never be greater than 90 degrees. The light for which the eye is most sensitive, and for which the lenses of the microscope are corrected, is the yellowish green with $\lambda = 0.00053$ millimeters. Introducing these quantities in (4), we have for visual observation with dry immersion:

$$R = \frac{2 \times .95}{0.00053} = 3580 \qquad (5)$$

which, since λ is in millimeters, represents the maximum number of lines per millimeter which may be resolved. From (3) we have for the distance between these lines (center to center), that is, the smallest distance which such an objective can resolve under the given conditions:

$$d = 0.00028 \text{ millimeters} \qquad (6)$$

For visual observations this represents the limit of resolving power, unless an immersion type of objective is used. For such, the maximum numerical aperture (with oil of cedar) is 1.40, whence by a similar calculation (4) and (3) give respectively:

$$R = 5300 \text{ lines per millimeter} \qquad (7)$$

$$d = 0.00019 \text{ millimeters} \qquad (8)$$

Distances smaller than these are incapable of resolution by visual observation.

While the statement last made is true in a general sense, it is not strictly true, for objectives have actually been constructed with a numerical aperture as high as 1.60, using monobromnaphthalene with n = 1.66 as an immersion medium. However, only a few of such objectives have been made, and their use is attended with considerable difficulty. Owing to the extremely close working distance the outside hemispherical lens of the system must be mounted in a very delicate manner, and there is great danger of disturbing its adjustment through contact of the lens itself with the object under examination.

By utilizing the photographic plate, which has maximum sensitiveness for the shorter wave-length blue rays, it is possible to increase resolving power accordingly. For this it is necessary to employ a ray filter which will transmit blue light, such as the Wratten "C" filter, which transmits light of dominant wave-length $\lambda = 0.00045$ millimeters.

Hence from (4) and (3) for photographic resolving power with dry immersion, we have:

$$R = \frac{2 \times .95}{.00045} = 4230 \text{ lines per millimeter} \qquad (9)$$

$$d = 0.00024 \text{ millimeters} \qquad (10)$$

Photography may be successfully used with an immersion system, for with equal magnification the ratio of the illumination of two objectives is equal to the ratio of the squares of their respective numerical apertures, so that with an immersion system the exposure time may actually be shortened.

With an immersion system using oil of cedar as above, we have from (4) and (3) for the maximum photographic resolving power:

$$R = 6230 \text{ lines per millimeter} \qquad (11)$$

$$d = 0.00016 \text{ millimeters} \qquad (12)$$

No great increase in resolving power beyond this is attainable except by the utilization of light of still shorter wave-length, i. e., ultraviolet light, and for this an entirely different instrumental equipment is necessary. Ordinary optical glass is opaque to light of wave-length shorter than $\lambda = 0.0003$ millimeters, and all lenses must hence be constructed of quartz or fluorite. Illumination is obtained from the lines in the spark spectrum of cadmium or magnesium with wave-length about $\lambda = 0.000275$ millimeters, a prism spectroscope being necessary to isolate the desired lines. As at present constructed, objectives using glycerine immersion, have a numerical aperture of 1.25, which is equivalent to a numerical aperture of 2.5 with ordinary yellowish green light. Thus, by the use of ultraviolet light the resolving power may be practically doubled. But unless ultraviolet light is used, we may consider that the minimum distance between two lines L_1 and L_2, which may be separated photographically, is of the order of 0.00016 millimeters (1/160000 inch).

It is to be noted that (4), the expression for R has been obtained entirely without consideration of the eyepiece or magnification. In other words, the resolving power of the microscope depends upon the objective (and the source of light) and is entirely independent of the degree of magnification. In fact, it is possible to conceive of a microscope with lower magnifying

power that will show smaller details than one with higher magnifying power.

It is true that the objective itself produces a magnified image of the object, and the degree of magnification, generally referred to as initial magnification, depends upon various factors, such as the focal length, the tube length of the instrument, etc. The magnified image is, however, not conveniently observable and it is necessary to introduce an eyepiece for further magnification, thus producing the enlarged virtual image $P_1''P_2''$, Fig. 1, which the observer sees. The total magnification produced by the combined action of the objective and eyepiece is what is commonly spoken of as "the magnification" of the instrument. This is usually given in the manufacturer's catalogs in terms of the combination of a certain objective, eyepiece, and tube length. When the virtual image $P_1''P_2''$ is seen at the normal distance of distinct vision, 25 centimeters (or the image projected on the ground glass focusing screen at a corresponding distance from the rear focus of the eyepiece), the magnification is equal to:

$$\frac{250 \times l}{f_o \times f_e}$$

where l = the optical tube length, f_o and f_e the focal lengths of the objective and eyepiece in millimeters, respectively. Since the tube length may not be accurately known by the observer, and because of different methods of calculation of constants of lenses by their respective makers, the actual magnification may be uncertain. If such is the case, the simplest and best method is to discard catalog values entirely and measure the magnification directly by using the stage micrometer. It is desirable to prepare a table giving the magnification obtained by various combinations of objectives and eyepieces with suitable projection distances, the position of the ground glass on the graduated base of the instrument being included. If this is done once and for all, settings can be quickly made for any given magnification, and there need be no doubt regarding the magnification actually obtained.

Distances of the order of d given above are invisible to the unaided eye, and we must consider the limiting total magnification necessary to utilize the full resolving power of the objective. This will be considered both for the eye, and for the photographic plate.

since the latter, because of the size of the silver grains in the emulsion, has a resolving power of its own.

Just how small an object or distance can be discerned by the normal eye depends upon a number of factors, the shape of the object, the manner in which it is illuminated, the contrast between it and the background, etc. Under proper conditions an exceedingly small object may be perceived. A very minute point of light is readily visible provided its intensity is sufficiently great. This is realized when we recall that a brilliant star, which subtends an inconceivably small angle, is easily seen by the unaided eye. Dark lines on a white background, separated by a space equal to their width, may be just separated by the normal eye when the distance from center to center subtends an angle of about 65 seconds. This is about the extreme limit. Two black circular dots, separated by their diameter, may be distinguished as such when their centers subtend an angle of 120 seconds. Hence, for a reasonable average, we may assume the smallest angular distance which can be just distinguished by the average eye to be 90 seconds = 1 minute 30 seconds.[4] Such an angle represents a distance of 0.11 millimeters at the distance of normal distinct vision. Hence, the above distance d from (8) will require magnification,

$$\frac{0.11}{0.00019} = 580 \text{ times},$$

before becoming theoretically distinguishable to the observer's eye.

Therefore assuming absolute perfection of the optical parts of the microscope, a magnification of 580× should just make visible the smallest details of structure revealed by the objective, and no increase in magnification beyond this can reveal further details. It is to be understood that this is the extreme limit of visibility, and because of imperfections of lenses, lack of centering, adjustments, etc., this theoretical limiting magnification must be considerably exceeded; and we may regard 800× to 900× as the practical limiting magnification necessary to secure full advantage of the resolving power given by the highest power immersion objectives in general use. Magnification beyond this value will reveal no further details, but only serve to separate those already visible, i. e., is merely the equivalent of enlargement.

From this we conclude that for each objective there is a

[4] This is equivalent to the diameter of a 25-cent piece seen at a distance of 180 feet.

certain "useful magnification" which is just sufficient to show full detail resolved by the objective. While greater magnification will render such detail more easily seen by the eye,—with less strain,—no new element is added to the picture, and such magnification has been called "empty magnification." From the above we may calculate the useful magnification M for a given objective when observations are made visually. At the theoretical limit of vision the angle subtended by d as resolved by the objective equals,

$$\frac{90 \text{ seconds}}{M}$$

whence,

$$\frac{90 \text{ seconds}}{M} = 206265 \frac{\lambda}{2 \text{ N. A.}} \cdot \frac{1}{250}$$

and

$$M = \frac{2 \text{ N. A.} \times 90 \times 250}{\lambda \times 206265^*}$$

Assuming $\lambda = 0.00053$ millimeters for visual observations, and introducing a factor of 1.5 to cover imperfections of lenses, errors of adjustment, etc., this reduces to,

$$M = 620 \text{ N. A.} \qquad (13)$$

which gives M, the useful magnification equal to 600 to 700 times the numerical aperture. It is to be understood that this is only approximate, and serves to indicate the proper magnifying power for a given objective. Obviously the visibility of any structure depends much on its configuration and contrast so that a hard and fast rule is not permissible.

In photographic work, because of the inevitable loss of fine detail in the process of reproduction, we are concerned with how much the details may be magnified before the appearance of sharp focus is lost. If we regard 0.25 millimeters as the maximum dimension to which the smallest distance resolvable on the object ($d = 0.00016$ millimeters) may be magnified in the image or on the photograph, then a magnification of $0.25/0.00016 = 1600$ times is proper; and we may consider this as the limit of useful magnification. If we are satisfied with 1 millimeter for the reproduction of the smallest distance d on the object, then a magnification of $1/0.00016 = 6250$ times may be used. However, at this magnification the details already visible at the lower power are merely

*The quantity 206265 used in the above equations is the number of seconds of arc in 1 radian, and is introduced as a factor necessary for conversion of linear to angular measure.

separated still more without any new being added, and such photographs, unless viewed from a distance, appear somewhat fuzzy and out of focus. Such fuzzyness is not due to incorrect focusing, but to lack of resolving power, the smaller details which, if present in the photograph would give the appearance of sharp focus, being beyond the ability of the objective to reproduce in the image. Hence, as a practical magnification, we may take a value somewhere between these two; that is, at 2000× to 3000×, and this may be regarded as the limiting useful magnification for the highest power objective (N. A. = 1.40).

The author does not wish to discourage the use of high magnification, but on the contrary to show in what respect it is useful. While it is true that no more detail may be visible at 3000× than at 1000×, that detail is much more easily seen at the high magnification. It is not a question of *what can be seen,* but of *how easily can one see it,* and this is why high power photomicrography is valuable. But there is a sensible limit even here and nothing is gained by exceeding it.

Having thus far considered resolving power as a function of the optical arrangement of the microscope and the ability of the human eye to distinguish minute distances, it will be in order to investigate what limitations are introduced through the use of the photographic plate which, because of the nature of the emulsion, limits the fineness of detail that can be sharply reproduced.

The transition from light to dark in the photographic reproduction of lines and points on a light ground, or bright details on a dark ground, is more or less gradual and indefinite and causes very minute closely packed lines or dots to merge one into the other. Thus, the photographic plate exhibits a resolving or defining power which depends upon the size and distribution of the silver grains in the sensitized emulsion. This is taken as the distance (actual) separating two minute images which are just separable on the developed plate. It is by no means a simply determined quantity, but depends upon various factors, of which the following are the most important:

1. Turbidity, which results from the scattering power of the silver grains in the emulsion, and which causes a spreading of the image beyond its theoretical outlines, tending to diminish resolution. Turbidity depends upon the grain size as affected

by the exposure time and the action of the developing agent.

2. Contrast, which is dependent upon the length of development, the nature of the developer, the type of plate, and the wave-length of the light employed.

3. Opacity, which limits the extent to which turbidity can act, since scattered light cannot travel far in an opaque medium.

The important question of photgraphic defining power has been studied by various investigators, Mees (*Proceedings* Royal Society, A. 83, p. 10), Huse (*Journal* Optical Society, 1, p. 119), Nutting (*Photographic Journal,* 1914), Ross (*Astrophysical Journal* 52, p. 201), and others. Obviously the whole question depends upon the nature of the plate itself. Process plates, which are generally fine grained and distinguished for their capacity to give sharp reproductions, are very "hard" working and have a comparatively small turbidity factor, while the contrast is high. Rapid or "fast" plates as a rule are "soft" working, coarse grained, and show a greater spreading of the light action consequent on a lower contrast factor and a greater turbidity factor. The spreading, however, does not necessarily depend on the size of the grain or the plate, some fine grained plates give a greater spreading than others with a coarser grain. For a fine grained emulsion, such as the Seed Lantern plate (Yellow Label) the photographic images of two fine lines on the plate will just be resolved if they are separated by 0.018 millimeters; while with a coarse grained emulsion, such as the Seed Graflex plate, a separation of 0.04 millimeters is necessary; and under the same conditions the Wratten and Wainright Panchromatic plate requires a separation of 0.032 millimeters. Huse found (*op. cit.*) that the nature of the developing agent was a most important factor; and that with Seed Lantern plates the resolution varied from 0.013 millimeters for pyro developer containing caustic alkali to 0.021 millimeters for Edinol; hydrochinone and metol giving about 0.016 millimeters. Also that for three types of plates, the normal or blue sensitive, the isochromatic, and the panchromatic, light of short wave-length ($\lambda = 0.00045$ millimeters) gave the greater resolution; this falling off slightly with green light, but being regained again in the red with the panchromatic.

As the extremely fine grained type of plate is rarely used in photomicrography we may consider a separation of 0.030 milli-

meters as the average value for the distance between the photographic images of two fine lines which may just be separated. Hence, the lowest magnification required to reproduce all possible fine details of the image on the photographic plate will from (12) be equal to,

$$\frac{0.030}{0.00016} = 190.$$

This is to be considered the theoretical limit. Practically, however, on account of imperfections of lenses, errors of focus, etc., a magnification of at least 250× to 300× will be required to obtain full resolution on the developed plate. With an objective of lower numerical aperture, giving less resolving power, a proportionately smaller magnification will be sufficient to show all details resolved under such conditions.

From what has preceded it will be apparent that the criterion of fineness of grain in determining the desirability of a particular plate for photomicrography is rather pointless, for the ordinary plate is capable of registering much finer details than exist in the image that is projected on it in any work with high magnification. At 1000× the distance d in (12) is increased to 0.16 millimeters, while the coarsest grained plate is capable of resolution down to 0.04 millimeters.

So far the metallographist has not taken full advantage of the possibilities of enlargement. Ordinarily with high magnification, say at 2000×, only a very limited area of the specimen can be included in the photograph, and due to lack of flatness of field all of this may not be sharply in focus. It is easily possible to enlarge a well made negative taken on a fine grained plate some six or seven times before the size of the silver grains in the emulsion become objectionable. With careful manipulation, using a glossy surface bromide paper, it is possible to obtain a 24×30 inch enlargement[5] from a 4×5 inch negative which will show a much greater area at approximately the same high magnification. Naturally the negative must be made with greatest care to ensure sharp definition and focusing with a low power eyepiece at a magnification of 200× to 400× in order to secure a large field. A fine grained slow plate should be used.

[5]Such an enlargement could obviously be obtained directly if the microscope were provided with a long bed and a large enough bellows extension, but a full size negative would have to be made and the inconvenience of handling and the expense would be almost prohibitive

While the resulting enlargement thus made will not have the absolute fineness of detail shown in the direct 2000× micrograph, still it will not be lacking in detail and will show many peculiarities and characteristics of structure, especially their relation to each other, that might be entirely missed in the customary small print at the same magnification. The author believes thoroughly in large photographs and regards the "postage stamp" variety as a fruitful source of error and misjudgment in studying the structure of a given specimen.

In concluding this discussion there are several points which should perhaps be further emphasized. It is to be noted that the resolving power given above for various kinds of objectives has been calculated on theoretical grounds, and may be regarded as being attainable only under certain definite conditions. In deriving the Abbe formula,(2), it has been assumed that the object consists of alternate black and white lines of equal width, and for structures of this character the formula is presumably correct. Any departure from such structure, however, such as spaces wider than lines, or vice versa, affects the diffraction pattern produced by the object, and in turn affects the resolving power. Thus, considered practically, the fineness of detail visible depends upon its configuration as well as upon the optical constants of the objective. With metallurgical objects the structure is rarely, if ever, uniform, and generally varies greatly from one part to another. Hence the resolving power actually obtained may differ considerably from that given by calculation.

To close this paper without mention of the work of Lucas[6] would mark the author guilty of lack of appreciation of the most successful high power photomicrography yet produced. Lucas has demonstrated beyond all question the possibility and value of photography at extremely high magnifications. The ease and clearness with which the hitherto unsuspected details of structure are revealed, particularly in hardened steels when extended to other metals and alloys must advance very materially our concepts of the structure and constitution of metals.

---

[6] "High Power Photomicrography of Metallurgical Specimens," TRANSACTIONS, American Society for Steel Treating, November, 1923, Vol. IV, No. 5, page 611.

"Microstructure of Austenite and Martensite," TRANSACTIONS, American Society for Steel Treating, December, 1924, Vol. VI, No. 6, page 669.

SPECIFIC EFFECT OF ALKALIES IN CARBURIZING COMPOUNDS

By Hugh Rodman

Abstract

This paper presents the results of certain laboratory tests made on various compositions of carburizing materials.

The energizing effect of carbonate additions varies with the position of the alkalies or alkali earths in the periodic system. It was noted that the energizing effect increases with the increase of atomic weight of alkali earth and decreases with the decrease of the atomic weight of the alkalies.

IT is common practice to add alkali carbonates or alkali-earth carbonates to charcoal or coke in order to increase the effectiveness of these carbons when they are used for the carburization of steel. No satisfactory explanation of this energizing effect of the carbonate has been offered, and none is offered here, but the usual assumption seems to be that the effect is due to the reduction of the carbonate with the subsequent formation of carbon monoxide, this gas being the active carburizing agent. The object of this paper is to call attention to some laboratory tests which indicate that the carbon monoxide due to carbonate reduction is less of a factor than is the particular metal oxide remaining after the reduction. The qualitative effect, or specific effect, of each of these metal oxides apparently varies with the position of the metals in the periodic system.

Materials Used in the Tests

Some preliminary tests indicated the necessity of using practically pure carbon. Discordant results were obtained with coke containing the usual eight or ten per cent of ash, and even with charcoal containing two or three per cent of ash. Charcoal was objectionable also because of its inherent carburizing capacity. The carbon used contained less than half of one per cent of ash, about seven per cent of volatile hydrocarbons when heated to

The author, Hugh Rodman, member A. S. S. T., is president of the Rodman Chemical Co., Verona, Pennsylvania.

1700 degrees Fahr., and had practically no carburizing capacity when used alone.

The carbonates tested included all those of the commoner alkalies and alkali-earths. Some tests were also made upon other carbonates, most of them ineffective. Those recorded here are the chemically pure or technically pure anhydrous carbonates of lithium, sodium, potassium, magnesium, calcium, strontium and barium. None of these contained more than one per cent of impurity.

In some instances use was made of a weak solution of molasses in water to bind the carbon and the carbonate together. When heated, this solution charred to about five per cent of practically pure carbon.

Tests were also made upon several commercial carburizing compounds consisting of charcoal and coke to which had been added five to twenty-five per cent of a carbonate or mixture of carbonates, usually sodium carbonate, calcium carbonate and barium carbonate. Results obtained with these commercial mixtures agreed fairly well with those obtained with simpler mixtures, but they were difficult to interpret because of the use of impure carbons and a mixture of carbonates.

Mixing the Carbonate and the Carbon

Tests were made with varying amounts of each carbonate, the carbon being held constant, and the results agreed with those reported except when excessive amounts of carbonate were added. There seems to be a maximum energizing effect possible with each carbonate and also a maximum effective carbonate addition, but these indications are masked in some instances by the inability of the steel to absorb the carbon as fast as offered. In the tests reported ten per cent of each carbonate was used, that is, ten parts by weight of carbonate to ninety parts of carbon. It was believed this amount of carbonate was large enough to give qualitative indications and yet not reach the maximum energizing effect of the carbonate; also to be within the absorptive capacity of the steel.

Batches of material were mixed in three ways. In the first, powdered carbon and powdered carbonate were simply mixed together. In the second, the powdered mixture was wetted with a weak

water and molasses solution and molded into small pellets like shoe buttons, then dried. In the third, fragments of carbon about a quarter inch in size were painted with a mixture of the carbonate and weak water and molasses solution, then dried. Tests made

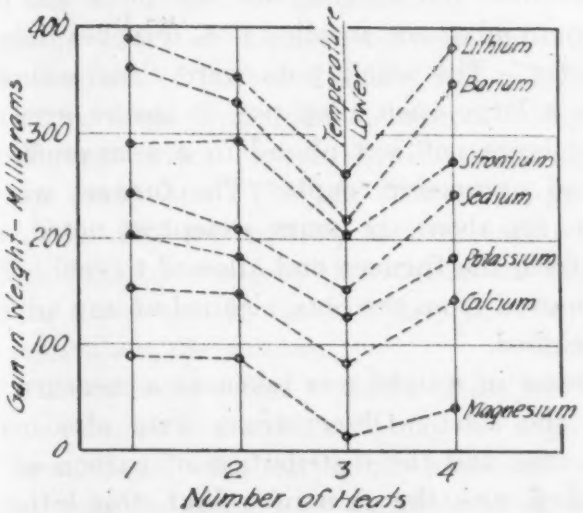


Fig. 1—Curves Showing Gain in Weight of Specimens Carburized in Compounds Containing Carbonates of the Elements Indicated. Pure Carbon was Used in Making Mixtures.

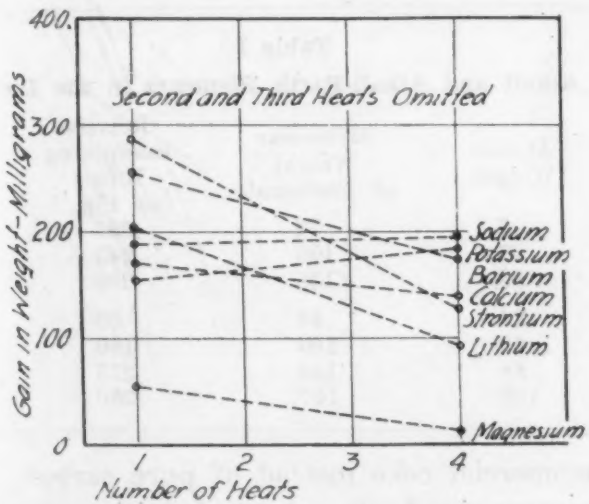


Fig. 2—Curves Showing Gain in Weight of Specimens Carburized in Compounds Containing Carbonates of the Elements Indicated. Commercial Coke was Used instead of Pure Carbon.

with these various mixtures gave concordant results except for magnesium carbonate, which was erratic in the finely powdered mixtures. The results indicated in Fig. 1 and Fig. 2 were obtained with the material prepared in the third way.

Testing the Mixtures

Pieces of steel approximately ¾ inch wide, $\frac{3}{16}$ inch thick and 2½ inches long were cut from one bar of S. A. E. 1015 stock. These were cleaned and weighed and one piece was packed in each of the carbonate mixtures, in alloy pots 6 inches deep and 2 inches inside diameter. The small pots were then sealed and all put together into a large open alloy pot, to insure even heat distribution, and the large pot was placed in a semi-muffle furnace close to a calibrated pyrometer couple. The furnace was held at 1700 degrees Fahr. for about six hours, except as noted, when the pots were drawn from the furnace and allowed to cool. The test pieces were then removed from the pots, cleaned of any adhering material and again weighed.

The increase in weight was taken as a measure of the carbon absorbed by the steel. Observations were also made upon the depth of the case and the distribution of carbon in the case, but as these checked with the gain in weight, this latter was used as a means of plotting results. The results are indicated in Fig. 1. The discordant results obtained with similar material except for

Table I

Position of Alkali and Alkali-Earth Elements in the Periodic System

	Atomic Weight	Molecular Weight of Carbonate	Relative Energizing Effect See Fig. 1	% Carbon Dioxide in Carbonate
Lithium	7	74	385	81
Sodium	23	106	245	57
Potassium	39	138	200	44
Magnesium	24	84	50	72
Calcium	40	100	150	60
Strontium	88	148	275	41
Barium	137	197	350	30

the use of commercial coke instead of pure carbon, are given in Fig. 2. Four successive heats were made with each mixture, fresh test pieces being used each time, the mixture being unchanged.

Observations

When pure carbon is used with moderate additions of alkali carbonates or alkali-earth carbonates for carburizing steel, the

energizing effect of the carbonate addition varies with the position of the alkali or alkali-earth in the periodic system. See Table I. It will be noted that the energizing effect increases with the increase of atomic weight of the alkali-earths and decreases with the increase of atomic weight of the alkalies.

The energizing effect of the carbonates apparently is not influenced by the amount of carbon dioxide, and consequent carbon monoxide, resulting from carbonate reduction. Magnesium carbonate contains much more carbon dioxide than does the same weight of barium carbonate. This conclusion is supported by the fact that some reducible carbonates, as iron carbonate, have no energizing effect, and by the fact that oxides or hydroxides, for instance, calcium oxide and hydroxide, may be effectively substituted for the equivalent carbonates.

As all of the carbonates are reduced under carburizing conditions to the corresponding oxides it may be argued that tests should have been made with carbonate additions calculated to reduce to equal weights of oxides. Some tests of this sort were made and checked against those reported. The exact figures changed somewhat but the apparent relation to the periodic system remained.

Educational Section

These Articles Have Been Selected Primarily For Their Educational And Informational Character As Distinguished From Reports Of Investigations And Research

THE CHEMISTRY OF IRON AND STEEL*

By F. T. Sisco

Abstract

Wrought iron is made by melting pig iron in a reverberatory furnace and oxidizing the carbon, manganese, silicon, and phosphorus with iron ore. When the charge is purified the metal is removed from the furnace as a pasty ball and the slag squeezed out. The rolled bars of wrought iron, alone or with steel scrap, are used as melting stock in the crucible process. This is a melting and alloying operation, very little refining being done. Most defects in steel originate in melting and refining, and are due to the reaction between oxides and gas in the metal and deoxidizers and recarburizers. A few defects originate in pouring and rolling or forging. The principal defects, non-metallic inclusions and blowholes, result from oxidation, thus acid Bessemer steel which is oxidized the most in refining will contain the largest amount of defects. The other steels in the order of their freedom from defects are basic open hearth, acid open hearth, acid electric, basic electric, and crucible steel.

The Chemistry of Wrought Iron and Crucible Steel

THE manufacture of wrought iron and crucible steel ranks among the oldest known processes for making steel. In their essential features both processes are the same today.

The manufacture of wrought iron is known as puddling and the finished product is called puddled bar or muck bar. In the manufacture of the best crucible steel muck bar is used as a base.

*This is the last instalment of this series of articles. The first, second and third instalments appeared in the February, March and April, 1925, issues of Transactions, pages 197, 363 and 494, respectively.

The author, F. T. Sisco, member A. S. S. T., is metallurgist, Air Service, War Department, McCook Field, Dayton, Ohio.

General Features of the Puddling Process

The puddling furnace is a reverberatory furnace with a horizontal or nearly horizontal hearth which is lined with iron oxide. The common size furnace is 500 pounds. The pig iron used contains about 1.00 per cent silicon, about 0.50 per cent manganese, less than 1.00 per cent phosphorus and less than 0.100 per cent sulphur. The pig is charged into the hearth and melted as rapidly as possible. Silicon and manganese are oxidized first. With a low temperature phosphorus is eliminated next, and finally carbon is removed.

As the percentage of carbon becomes low, the melting point of the iron raises progressively until finally the temperature of the furnace is not sufficient to keep the charge molten and it becomes pasty and then almost solid. By means of a long iron rod, the puddler gathers up about 150 pounds of the iron and rolls it into a semi-solid ball. This ball is then taken to the squeezer where most of the entangled slag is forced out. After squeezing, the wrought iron is rolled into bars.

The finished product usually contains less than 0.20 per cent carbon, although up to 0.30 per cent may be present; and a small amount, less than 0.20 per cent, manganese. Silicon is almost entirely eliminated and about 70 per cent of the contained phosphorus removed. The finished metal will contain between 0.010 and 0.100 per cent phosphorus depending upon the amount in the pig iron. About 30 per cent of the initial sulphur is found in the finished bar.

Due to the character of the puddling process considerable slag is mixed with the iron. After squeezing, about 1 per cent slag, sometimes a little more, is found in the wrought iron. On rolling, these slag particles become elongated and result in a fibrous structure.

The Chemistry of Wrought Iron

The manufacture of wrought iron is an oxidizing process. Before charging the pig iron, the hearth is fettled with iron oxide in the form of roll scale or high grade iron ore. As soon as the pig iron is melted, which takes 10 to 15 minutes, about 90 per cent of the silicon in the pig iron has been eliminated. In another 5 minutes more than 90 per cent of the manganese has

also been oxidized. The reactions by which these two elements are eliminated are the same as in any oxidizing process:

(1) $2\ FeO + Si \rightarrow 2\ Fe + SiO_2$

(2) $FeO + Mn \rightarrow Fe + MnO$

All of the oxidizing reactions are the same whether the iron oxide is present as FeO, Fe_3O_4, or Fe_2O_3, or as mixtures of these oxides.

As soon as the pig is melted, more iron ore is added and the bath is cooled by dampering the furnace. The silicon and manganese have been oxidized by this time so a comparatively low temperature is desired to facilitate the oxidization of the phosphorus, reaction (3a and 3b)

(3a) $5\ FeO + 2\ P \rightarrow 5\ Fe + P_2O_5$

(3b) $3\ FeO + P_2O_5 \rightarrow (FeO)_3(P_2O_5)$

which passes into the slag as ferrous phosphate (3b).

As the temperature increases the oxidation of the carbon becomes rapid, reaction (4a and 4b)

(4a) $FeO + C \rightarrow Fe + CO$

(4b) $CO + O \rightarrow CO_2$

producing a violent boil. The slag must be kept very basic by a large excess of ferrous oxide, FeO, to prevent the carbon monoxide formed by reaction (4a) from reducing the phosphoric acid, P_2O_5, held in the slag to phosphorus.

When practically all the carbon is removed the metal begins to "come to nature." This condition exists when the boil has practically ceased and the metal is beginning to become pasty on the bottom of the furnace. It is then ready to "ball up" and remove for squeezing.

The puddling furnace slag is composed of ferrous silicate, a little manganese silicate, ferrous phosphate and free ferrous oxide.

The Chemistry of the Crucible Process

The chemistry of the crucible process is very simple. The operation consists in charging wrought iron and various metallic alloys into a graphite and clay crucible, melting the charge and, after a period of quiet, teeming the contents of the crucible into an ingot mold. In the manufacture of high grade crucible steel, wrought iron (also called puddled bar or muck bar) is used. In some plants steel scrap is mixed with the muck bar. The charge is usually about 100 pounds. The various alloying elements such

as ferromanganese, nickel, ferrochromium, ferrovanadium or ferrotungsten, and additional carbon in the form of charcoal, or washed metal, are added to the crucible.

Some makers of crucible steel use different "dopes" or scavengers whose purpose is probably to assist in cleansing the metal or to make the slag more fluid. These dopes include salt, manganese oxide, and such.

In about two and one half hours after the crucible is placed in the melting hole, the melting is complete. After this about 45 minutes of "dead melting" follows. During this time the steel is allowed to stand quietly in the pots. The object of the dead melting or "killing" is to give slag inclusions, oxides and gas the opportunity to rise to the top. During the dead melting period some carbon is absorbed by the metal from the crucible. Likewise some silica from the walls of the crucible is reduced to silicon and is absorbed by the steel.

In the crucible process there are no oxidizing reactions taking place. The whole process is simply one of melting and alloying the desired metals. The superior quality of crucible steel is due to five factors:

(1) There is no oxidization hence there is no opportunity for the reaction products of oxidization to become entrapped in the metal.

(2) The period of rest or "dead melting" allows sufficient time for all suspended oxides or silicates, all included slag or occluded gas to leave the metal.

(3) There is some reduction of silica contained in the walls of the crucible to silicon. Although this reduction may be small in amount; when the effect of silicon is added to the effect of the manganese, the amount of deoxidation and degasification taking place in the dead melting period is sufficient to deoxidize and degasify completely.

(4) The crucible slag is usually acid in character and has a high surface tension, thus preventing easy disintegration and resulting emulsification.

(5) The steel is made in small lots and from carefully selected materials. Each melt of 100 pounds receives as much care from the melter as it would if it were 100 tons.

For many years crucible steel has enjoyed the reputation of

being the finest product of any steel making process. Only recently and then not often, has it been approached by the electric process.

Defects in Iron and Steel

At every stage of the manufacture, from the time the scrap or pig iron enters the furnace, until the finished piece is ready for shipment, there are numerous opportunities for the metal to become defective either physically or chemically. Defects in iron and steel form such a vast and important study that it is practically impossible to describe, even briefly, more that a few of them in these pages. It has only been realized recently that extremely minute amounts of some impurities and foreign matter could exercise a vast importance on the quality of iron and steel. Even now the importance of thoroughly cleansing the metal to free it from foreign matter, "dirt" and gas, is given scant attention in many steel works. Equally important with the dirt and gas occurring in melting and refining are the defects liable to be introduced at some stage of the casting or hot working. Defects in iron and steel may be divided into two general classes:

(1) Defects introduced into the metal at some stage of melting or refining, including:

(a) Non-metallic inclusions, resulting from the reaction between impurities and deoxidizers and recarburizers;

(b) Solid inclusions introduced mechanically through contact with slag, refractories, ladle linings and the like;

(c) Occluded or dissolved gas.

(2) Defects, mostly structural and physical, introduced into the metal at some stage of casting or hot working, including:

(a) Ingot defects, such as pipes, cracks, scabs and ingotism;

(b) Seams, cracks, laps and hair lines, etc., resulting from the distortion in hot working of some defect already in the metal;

(c) Segregation.

It should be clearly understood that there is no sharp dividing line between class 1 and 2; defects introduced into the metal during melting and refining (class 1) very often cause the defects in the ingot or rolled billet and bar. In fact seams and hair lines are almost always caused by some defect introduced into the metal in melting and refining. The division above is purely arbitrary and is made to simplify discussion.

Defects Introduced Into the Metal During Melting and Refining

In general it is true that most of the defects found in the finished iron or steel product originate in the melting furnace or ladle, before the metal is teemed into the mold. It is also true that the final quality of iron or steel is determined almost wholly by the melting and refining practice used.

Solid Non-Metallic Inclusions from Reaction Products Introduced in Melting and Refining

The most abundant and the most important defects introduced in melting and refining are those classified as solid non-metallic inclusions. These include particles of slag or dirt entrapped in the metal, silicate reaction products from the manganese and silicon additions, and oxides, entrapped as such and not forming silicates. The latter includes manganese and ferrous oxides and silica. Although manganese sulphide is not an oxide it may be included here.

The amount of these inclusions depends almost wholly on the nature of the process and to a great extent on the care used in melting and refining. In general acid Bessemer steel will contain the largest number of inclusions, basic open hearth ranks next and acid open hearth next. The three processes in which inclusions should be absent or very nearly so are the acid electric, basic electric and crucible processes. Because of the nature of the process, crucible steel should be very clean. Well made electric steel should also contain a negligible amount of inclusions.

In discussing the chemistry of the various steel making processes we have taken up deoxidation at some length. It will not be necessary to repeat those reactions here. The product of the acid Bessemer process will contain, before deoxidation, the largest amount of dissolved ferrous oxide and in this process the addition of deoxidizers will produce the largest amount of reaction products, manganese oxide and manganese and iron silicates. Although these products mostly tend to separate from the steel to join the slag, two factors work against this complete separation. These are lack of time and excess of dissolved oxides. In the acid Bessemer and in the acid and basic open hearth processes only a few minutes elapse after recarburizing and deoxidizing, before the ingots are teemed. Again, the larger the excess of included reaction products formed the less the likelihood of a complete separa-

tion. Therefore acid Bessemer steel should contain an appreciable amount of inclusions, and this has been found to be true.

Oxidation in the acid and basic open hearth is not so vigorous as in the Bessemer process, therefore, a much smaller quantity of dissolved ferrous oxide is present and a smaller quantity of reaction products will be found in the steel. This also, has been found to be the case in practice. In the electric and crucible processes, conditions make it impossible for solid non-metallic inclusions to be present in more than traces. In the first place a much smaller quantity of dissolved ferrous oxide will be present in the metal after melting, and in the second place deoxidizers and recarburizers are added to the metal while it is still in the furnace, thus increasing greatly the time available for the reaction products to leave the steel.

The reaction products found as solid non-metallic inclusions in steel are chiefly manganese silicate, ferrous silicate, manganese oxide and ferrous oxide. The last two are not common; probably, however, there is more present in the average steel than is now thought possible. Steel makers and steel users very often ignore what they cannot determine with a certainty, and as chemical analysis and the microscope often fail to defect or identify a solid non-metallic inclusion, its possible presence is commonly ignored.

Manganese and iron silicates are usually found associated together and often occur in areas of appreciable size, sufficiently large that they may be positively identified by microscopic examination. These inclusions may be recognized by the microscope as brown or brownish black elongated fibers in the longitudinal section and as rounded particles in the transverse section.

A solid non-metallic inclusion found in all iron and steel is manganese sulphide. This constituent, its occurrence and character has been discussed in detail in a previous installment. The amount of manganese sulphide present is dependent upon the amount of sulphur in the metal. We will not discuss ferrous sulphide further. In steels of commerce this impurity should be absent.

Solid Inclusions Introduced Mechanically Through Contact With Slag, Refractories, Ladle Linings and the Like

There is always a possibility of the metal trapping non-metallic inclusions from the slag used to refine the metal. In well made

steel, patches of slag of appreciable size should not be present. When they occur they are due to the mechanical intermixing of slag and metal, usually in tapping; the violent churning as the slag and metal pour into the ladle serving to break the slag into small particles which may remain entrapped in the steel if insufficient time is allowed for them to rise to the top. Slag inclusions from this source are prevented by tapping the metal before the slag and preventing, to a large extent, the mechanical intermixing of the two.

In all steel making processes particles, sometimes of appreciable size, may spall off the furnace refractories or ladle lining and contaminate the metal. In general when patches of the refractory furnace lining or bottom work loose they are apt to be of considerable size and will immediately rise to the top.

The contamination of the metal by particles of refractories may be wholly prevented by care in lining and repairing the furnace and ladle and by care in burning in the bottom. We may say, therefore, that the amount of inclusions thus introduced into steel will be negligible.

Occluded or Dissolved Gas

Most steels will contain traces of occluded or dissolved gases, principally hydrogen, nitrogen, and carbon monoxide. It is also possible for oxygen and carbon dioxide to be present as well. There is a possibility for hydrogen to be introduced into steel from the dissociation of water vapor in the air used for combustion. The nitrogen comes from the furnace gases and may be present in steels made by the acid Bessemer and the acid or basic open hearth process. In the electric or crucible process, little if any nitrogen has access to the metal. Nitrogen may be an extremely harmful impurity. It forms iron nitride which settles at the grain boundaries, destroys their cohesion and makes the metal brittle. Only a small percentage of nitrogen (less than 0.050 per cent) is necessary to reduce the ductility 30 per cent or more. Ferrotitanium is said to be very efficient in eliminating nitrogen and is used somewhat extensively in open hearth practice for this purpose. Ferrovanadium is also considered to remove this gas.

Little nitrogen is found in steel. Even in steel made by the Bessemer process where air is forced through the molten bath, nitrogen is not a common impurity. In acid and basic open hearth

practice the slag forms a blanket over the metal and prevents little if any nitrogen from being absorbed by the steel. Nitrogen is more often introduced into steel in such operations as welding or case carburizing.

In general, although there is always a possibility of nitrogen being present in steel made by an oxidation process, very little is encountered and except in isolated instances where enough of the gas is taken up to cause brittleness, most steels are free from all but traces.

Dissolved or occluded carbon monoxide gas is present in all steels where there was any oxidation of the carbon. The solubility of molten steel for carbon monoxide is slight and the small amount that is dissolved is mostly expelled on solidification or cooling through the mushy range. Most of the carbon monoxide gas resulting from the reaction between carbon and dissolved ferrous or manganese oxide escapes as soon as formed. There is, however, an appreciable amount dissolved in the molten metal. The small amount that does not escape in the interim between tapping and teeming the ingots is rejected by the metal as it cools further.

During the mushy stage, the metal in the mold is too viscous to allow the gas bubbles to rise, hence on solidification these bubbles form gas cavities in the ingot known as blowholes.

If there is some unreduced ferrous oxide in the steel when the ingots are teemed, this dissolved impurity may react with carbon to form carbon monoxide. This carbon monoxide, formed too late to escape, will cause blowholes.

Blowholes are common to nearly all steels and range in size from an inch or more in diameter down to those that are microscopic. The number of blowholes is in direct ratio to the amount of oxidation and in inverse ratio to the completeness of deoxidation and degasification. Thus acid Bessemer steel which is oxidized in melting and refining more than any other steel, is likely to contain more blowholes than acid or basic open hearth steel. As crucible steel is not oxidized in melting and is thoroughly "dead-melted" or "killed" before being poured it should be absolutely free from this defect. Electric steel because of its deoxidation period should also be free from blowholes. In general this holds true.

More blowholes will be found in low carbon steels made by the Bessemer and open hearth process than in medium and high car-

bon steels. This is because the low carbon steels are oxidized more to remove the carbon than those containing a larger residual amount of this element. In general alloy steels are usually free from blowholes. Most of the alloying elements are also efficient deoxidizers and degasifiers as well as valuable alloys.

In carbon steels the harm that may result from blowholes depends largely upon their location. As the carbon monoxide contained in these gas cavities is reducing in its action; if the blowholes are deep seated they will weld in rolling, thus closing up and eliminating the defect. If they are located near the surface they may become oxidized when reheated for rolling. If oxidized, they will not weld and a seam results. In most of the alloy steels blowholes will not weld, even if deep seated. In this grade of material, after rolling, the blowhole becomes an internal crack or hair line, depending upon its size. Except in low carbon steels (0.30 per cent and less) and only then if located well below the surface of the ingot, blowholes are an exceedingly harmful defect, one which gives the steel maker and steel user much trouble.

Carbon dioxide, oxygen and hydrogen are three gases about which very little is known, as far as their occurrence in steel is concerned. We have no way of easily and accurately determining if they are or not present in the metal. Molten iron or steel will absorb hydrogen readily but as it is probably only slightly soluble in the solid metal it is practically all expelled just before or during solidification. Oxygen can hardly exist in steel as the gas. Due to its great affinity for iron, manganese, silicon, carbon and other elements, it would probably form oxides as soon as taken up by the metal. About carbon dioxide, except that it has been detected in steel, we know almost nothing.

Defects Introduced Into Iron During Melting

So far most of our discussion of defects has been confined to those occurring in steel. In steel making processes, the very nature of the melting and refining reactions are such that many impurities and defects may be introduced into the metal. In the manufacture or melting of iron the very opposite is true. The blast furnace is a reducing medium, pure and simple. A large excess of carbon, and usually silicon and manganese, all three efficient deoxidizers and degasifiers are present in pig iron as soon as it melts and collects in the furnace hearth. There is no opportunity for oxidation

defects to be introduced. The only impurity forming an inclusion is sulphur, which is usually present as manganese sulphide. Occasionally iron sulphide is present and the iron becomes weak and brittle. Pig iron rarely contains suspended slag.

In remelting pig iron to make castings, the same holds generally true. The iron is melted in a cupola. The excess of coke necessary to melt insures that the atmosphere in the cupola will always be reducing, and the excess of carbon, manganese and silicon in the molten iron insures that oxidation defects can never become serious. Blowholes will occasionally be found in iron castings. The metal may become slightly oxidized in pouring. The iron oxide formed will react with carbon to form carbon monoxide gas which may become entrapped in the casting to form a blowhole. This defect is not frequent. We may say therefore that with the exception of manganese sulphide, pig and cast iron should contain no other defects in appreciable amounts.

Defects, Mostly Structural and Physical, Introduced Into the Metal at Some Stage of Casting or Hot Working

In the previous section it has been noted that most of the impurities and defects commonly found in finished steel, are introduced in melting and refining. This holds true for a great majority of them. Whenever a thoroughly unsound lot of steel is encountered, the cause can ordinarily be traced back to the melting and refining operation. In addition to the defects introduced in melting and refining, namely, solid non-metallic inclusions, slag and gas, there are a number of defects that may be introduced into the metal after it leaves the melting furnace. Chief among these are ingot defects including pipes, cracks, scabs and ingotism; defects in the finished section including seams, cracks, laps, and hair lines. Segregation may also be described as a defect in the cast or rolled section.

It is sometimes a difficult matter to differentiate sharply between defects introduced into the metal in hot working and those originating in the melting furnace and brought to light after rolling or forging. When surface seams, deep seams, and hair lines are encountered in the finished steel, there is always some doubt as to their source.

Ingot Defects; Pipes, Cracks, Scabs and Ingotism

It has lately been realized, in the manufacture of alloy and

other high grade steel, that good pouring practice is of vital importance in the production of a high quality product. Although inherently bad steel cannot be made better by the best pouring practice, a ladle of thoroughly deoxidized and otherwise good metal may be wholly spoiled by bad pouring practice.

The three variables that influence the quality of the ingot, assuming the metal to be first class, are mold design, temperature of pouring and rate of pouring. Octagon and fluted molds usually produce better ingots than square molds although the present practice of rounding the corners of square molds has greatly improved the quality of the square ingot. High grade steel is nearly always poured cold and as slowly as conditions permit. Lack of space will not allow an extended discussion of the above three points.

Among the ingot defects the pipe is one of the most important. Thoroughly deoxidized and degasified steel always shows a tendency to pipe. When steel does not pipe in solidifying it is a general rule that gas cavities (blowholes) will be present. Low carbon Bessemer and open hearth steels seldom pipe. There is a sufficient amount of dissolved gas which, when thrown out of solution on solidification offsets the natural contraction of the cooling metal. We may state as a general law, that sound steel always pipes to some extent, and when a pipe is not present blowholes are indicated and will nearly always be found.

In sound steels, therefore, the steel maker always has a pipe to contend with. Since it is a necessary evil he aims to have it in that part of the ingot where it may be cropped and thus scrapped with a minimum loss of metal. Therefore molds for high grade steels are so designed that this contraction cavity will occur in the uppermost quarter of the ingot. Many of the alloy and other high grade steels are cast in ingots "big-end-up" and a preheated brick known as a "hot-top" or "sink-head" placed on the top of the ingot. Then if the temperature and rate of pouring is closely controlled, the contraction cavity will be in the extreme upper part of the ingot, even up in the sink-head where it may be cropped after rolling. In the manufacture of those grades of Bessemer and open hearth steel that go into tonnage products, such as plate, structural shapes etc., there is no pipe formed and consequently the ingots are cast big-end down and no sink-head used. Casting big-end-down permits easy and rapid stripping. In connection

with the expression "big-end-up" or "big-end-down" a word of explanation may be advisable. All ingot molds are tapered slightly, being larger in cross section at one end. The taper is usually 0.1 to 0.2 inch per running foot. In big-end-down molds this taper permits mechanical stripping. In the big-end-up design the taper facilities stripping to a degree, and aids in keeping the pipe up in the top of the ingot.

Cracks and scabs are typical ingot defects. When steel is poured into a mold the metal in contact with the mold surface solidifies almost instantly. In solidifying, it contracts considerably. If the mold surface is slightly irregular this thin skin of solidified metal may attach itself firmly in certain spots. In this case the contraction is sufficient to cause rupture. If the steel is poured very hot the pressure exerted by the molten interior contents of the mold against this thin skin of solidified metal may also cause rupture. Again, some alloy steels are so tender that unless they are cooled down very slowly the difference in contraction between the relatively cool surface and hot interior will cause cracking.

Scabs are produced by particles of molten metal splashing against the mold wall in pouring and freezing there. If the steel is poured cold, the added metal may not be sufficiently hot to melt off these small slugs, and a scab results. As a rule these scabs are not serious as they may be chipped off before rolling. Scabs are usually known as cold-shuts. Scabs may be prevented by bottom pouring, which is practiced somewhat extensively with high grade steels. In this connection it may be noted that both top and bottom pouring have their advantages and disadvantages. Bottom pouring tends to produce an ingot with a clean surface free from scabs or cold-shuts but it also increases the liability of secondary pipe, which is a contraction cavity well down into the body of the ingot. Top pouring is effective in throwing the pipe well up into the top of the ingot but has the disadvantage of sometimes causing surface defects.

Ingotism is a form of coarse crystallization due to the very slow cooling of the metal through the solidification and transformation ranges. Obviously the rate of cooling is in a large measure dependent upon the initial temperature of the metal and the size of the mold. When the crystal size becomes excessively large the cohesion between the crystal masses is greatly reduced and the metal

is very tender. In extreme cases it is so tender that it tears in rolling or forging. Ingotism and its allied defect, columnar crystallization, may be totally broken up in hot working, although there are cases when the result is a banded structure.

Seams, Cracks and Hair Lines Resulting From the Distortion in Hot Working of Some Defect Already in the Steel

When steel is blowy these minute gas cavities elongate in rolling and form small cracks known as seams. Seams are not troublesome in the usual run of Bessemer and open hearth steels, as the blowhole if deep seated will weld together and thus eliminate the defect. In the alloy steels and in some high carbon steels these blowholes will not weld and a seam is the result. Hair lines are extremely minute seams resulting from the elongation of a very small blowhole. They range from 1/64 to ½ inch long and very often have no evident depth. Hair lines are very prevalent in some chromium and chromium nickel steels and are, no doubt, the cause of many fatigue failures.

In any steel, if the blowhole is close to the surface it may become oxidized in the soaking pit or reheating furnace when the ingot or billet is heated for rolling. An oxidized cavity will not weld. It simply becomes elongated and forms a surface seam. Most steels are likely to contain numerous very small blowholes near the surface of the ingot caused by the carbon monoxide gas that seeks to escape after the ingot is poured. The metal in contact with the mold wall freezes almost instantly, consequently the gas that is expelled has no opportunity to escape, or collect into larger bubbles.

Among the defects that are caused in the rolling mill may be mentioned fins, laps, slivers, over-fills and numerous others. It is beyond the scope of our discussion to describe these in detail. The most common of these defects are slivers, fins and laps. A sliver is a small piece of the metal that becomes loose and is rolled into the surface. It often results from rolling out a scab or cold-shut. If the piece of metal being worked does not go into the rolls exactly right, a small amount may be forced out between the rolls and produces a small amount of extra metal or fin on the sides. These fins are also known as over-fills. When overfilled very slightly the defect may escape notice and when the bar goes into

the next pass this overfill or fin is rolled down onto the bar and forms a lap.

Segregation

Segregation is such a vast subject and involves so many variables of composition, melting and refining practice, pouring practice and rolling practice that it cannot be discussed intelligently in a few pages. Steel is a mixture of several chemical elements and compounds. In addition it may contain appreciable amounts of foreign matter. Some of the compounds have solidification points differing considerably from the bulk of the metal and tend to concentrate in that portion of the ingot or casting last to solidify.

The principal chemical compound is iron carbide, Fe_3C. This compound tends to combine with iron to form a low melting eutectic, which freezes at about 2100 degrees Fahr. Pure iron freezes at about 2750 degrees Fahr. When the steel cools the pure iron freezes first and thus enriches the remaining liquid in carbon. This continues until the mass is solid. The whole procedure is very complicated. Describing the process in simple terms it may be said that the first metal to freeze is poor in carbon and the last to freeze is richer in carbon than the average. As solidification starts simultaneously in a large number of centers rejection of the liquid rich in carbon is confined to a relatively small area. As iron carbide tends to diffuse back into the portions poorer in carbon, this rejection of the carbon in solidification is practically counteracted. There is however, a very small amount of carbon that does not succeed in diffusing back. Consequently the last of the liquid to solidify will be comparatively rich in carbon. If, in a 14,000 pound ingot an average of only 0.00001 per cent would be permanently rejected and this 0.00001 per cent concentrated in the last 200 pounds to solidify it would increase the carbon content of this 200 pounds 0.07 per cent. In practice segregation is often much more than this.

As the upper part of the ingot, around the pipe, is the last to solidify, the segregated metal will be found here. Thus it works out, in normal practice, that when the steel maker scraps the piped section of the ingot he also scraps the segregated portion. This, in brief, is the mechanism of segregation, and holds for other elements as well as carbon. In general then, many of the compounds found in steel, such as the carbides, sometimes the sul-

phides and phosphides will tend to be rejected when the metal cools, and will concentrate in the portions last to solidify unless partly counteracted by diffusion. It has been found that the certain elements dissolve in the ferrite to form a solid solution. Nickel and molybdenum are examples of such elements, and thus do not segregate. Those elements such as manganese, chromium, tungsten and sometimes vanadium, which form carbides, will tend to segregate.

Non-metallic inclusions, unless their solidification point is very near that of the steel, will usually segregate. This is true of silicate inclusions. Manganese sulphide unless contaminated with iron sulphide and unless large in amount does not segregate appreciably. In certain kinds of steel the free ferrite (pure iron) will segregate. When non-metallic inclusions are located in the free ferrite, as is often the case, they will accompany the ferrite in its segregation. Iron phosphide when present in small amounts is in solution in the ferrite, and although it does not segregate in itself, will accompany the free ferrite. As a result, bands of free ferrite characteristic of some low carbon alloy steels will contain segregated non-metallic inclusions and will show phosphorus segregation.

We have noted that segregation usually occurs in that part of the ingot or casting last to solidify. Thus, in high grade steels it is found in the top 10 or 15 per cent of the ingot, and is scrapped with the top discard after rolling. In the manufacture of castings the gates and risers will contain most of the segregation which may thus be eliminated with a minimum of loss.

Other Defects in Steel

There are a few more important defects found in steel that have not been discussed. Among these may be mentioned "flakes" and "woody" fracture, a defect characteristic of some nickel and chromium nickel steels made by the basic open hearth or basic electric process. It is with some hesitation that we take up flake as this defect has been responsible for much controversy in metallurgical circles for the past five or ten years. Flakes and woody fractures are defects usually characterized by a coarse crystalline shiny or coarse crystalline dull woody fractures, although woody fractures have been observed in fine grained structures. When these defects are present the metal apparently has practically no

ductility at all. Much thought and study has been given to flakes and opinion has narrowed down to the consideration of this as an oxidation defect originating in melting and refining, and partially, though never wholly controlled by proper methods of pouring and handling the steel after the ingots are poured. The writer investigated one flake that contained three times the amount of nickel present in the steel. This would seem to indicate that nickel had segregated into this area although it has long been held that nickel does not segregate. It can be definitely stated that flake is a defect common to nickel and chromium nickel steels made by a basic process. It occurs more often in large ingots than in small and can be partially but never wholly eliminated by close control of the pouring practice. It is not uniformly distributed in an ingot. One section may be badly flaked while the rest of the metal is free from it. It is probable that the near future will clear up this now unexplainable defect."

A QUICK QUALITATIVE TEST FOR NICKEL STEEL BARS OR ALLOY STEEL BARS CONTAINING NICKEL WITHOUT THEIR REMOVAL FROM THE STOCK RACKS

By L. W. Spring and E. W. Hutchison

Abstract

This paper describes a rapid qualitative test for nickel in steel bars containing nickel. It has been found that 0.05 milligrams of nickel per cubic centimeter is the smallest quantity of nickel that can be determined with certainty. For a 1.25 per cent nickel steel, it becomes necessary to dissolve 4 milligrams of the steel to obtain a satisfactory precipitate with the dimethylglyoxime.

It is easily possible to differentiate between bars containing nickel and those without nickel, the time required when running several bars at once averaging less than two minutes per bar. The time for one bar alone is about five minutes. Such tests can be conveniently carried out on bars stocked in racks with ends exposed.

IN the December 20, 1923 issue of "Automotive Industries," H. C. Knerr described a test employed at the Naval Aircraft Factory to identify nickel steel bars which through accident had been mixed with carbon steel bars of the same exterior appearance. The test Mr. Knerr describes gives a red brown coloration on filter paper for carbon steels and a strawberry pink for nickel steels. For some time we have been using a qualitative test devised along the same lines to prevent the situation Mr. Knerr describes or the acceptance of any carbon steel on alloy steel orders by spot testing each bar in the stock rack, or as unloaded, marking the accepted bars with a special stamp. The factory uses only such bars as bear the proper mark.

Trying out Mr. Knerr's method of testing, with our steels, some containing as low as 1.25 per cent nickel with about 0.75 per cent chromium, we found the strawberry pink color so nearly like the red brown coloration of carbon steel that our men were unable to identify the nickel steel with the certainty desired. By the method we use, steels containing nickel give a red precipitate while

Of the authors, L. W. Spring, member A. S. S. T., is metallurgist and E. W. Hutchinson is chemist, Crane Co., Chicago.

carbon steels give only a yellow solution, thus eliminating any doubt due to personal idea of color.

Our test is as follows:— Cut 11-centimeter qualitative filter papers in eighths. Moisten a piece with two drops of nitric acid (sp. gr. 1.20) from a dropping bottle and a place on the ground end or otherwise cleaned surface of a bar. After papers have been placed in succession on four to ten bars, return to the first bar. If the paper on it shows an area of ¾ of an inch in diameter darkened by dissolved steel, enough material probably has been dissolved. Transfer the paper to a ¾ x 6 inch test tube and push it to the bottom with a glass rod. Rinse off the glass rod with 2 to 4 cubic centimeters of 5 per cent ammonium persulphate and remove from the tube. Do this in turn with the other papers. Shake the tube gently until the brown coloration on the paper disappears. In obstinate cases 1 drop of nitric acid (sp. gr. 1.20) will assist. Add 2 - 4 drops of ammonium citrate solution containing 40 grams of citric acid crystals dissolved in 60 cubic centimeters of ammonia (sp. gr. 0.90). Mix and add 2 - 4 drops of dimethylglyoxime containing ½ gram of dimethylglyoxime dissolved in 50 cubic centimeters of ammonia (0.90.) Shake for half a minute add 6 - 10 drops of glacial acetic acid and shake until the precipitate separates. The amount of acetic acid necessary is indicated by the disappearance of the deep coloration due to ferrous iron and dissolved carbon. After standing a minute, the red precipitate of nickel dimethylglyoxime rises to the surface leaving a clear yellow green solution beneath.

The limitations of the method were determined by adding a solution containing 0.05 milligrams of nickel per cubic centimeter to tests made on carbon steel bars. It was found that 0.05 milligrams of nickel is the smallest amount that can be detected with certainty. For a 1.25 per cent nickel steel, which is the lowest in regular use, it is necessary, then, to dissolve 4 milligrams of steel to obtain a satisfactory precipitate. Our nickel precipitates obtained by the method given are invariably larger that that given by the 0.05 milligrams of nickel added, which indicates that no difficulty will be found in dissolving from a steel bar sufficient steel to give the nickel test under the conditions outlined. Nor will the test indicate a nickel steel when only traces, i. e., less than 0.50 per cent is present.

We have tried combining the citrate and dimethylglyoxime solutions, but the precipitates have not been as satisfactory as when added separately, and we believe the procedure as given is justified by the more satisfactory and certain precipitates obtained.

By starting at the same time several bars as described above, a routine can be worked out by which a chemist can easily attain an average speed of less than two minutes per bar, working, of course on bars with ends already cleaned.

Our experiments indicate that there is no danger of an emery wheel in grinding carrying sufficient nickel from a nickel steel to give the nickel test to a carbon steel bar immediately following.

A routine is being worked out whereby as such alloy steels come to the plant an end of each bar will be freed from scale or rust by a short contact with a grinding wheel as the bars are taken from the car. The bars will then be placed in the stock racks with their ground ends flush. They will be tested as described above and stamped if found acceptable. This grinding and testing upon unloading is done to avoid extra handling, and therefore will cause little or no inconvenience to the shop.

No bar is to be worked up into product unless it bears on one end the laboratory's stamp of acceptance.

NOTES FROM THE U. S. BUREAU OF STANDARDS*

The Detection of Flaws by Magnetic Analysis

THE Bureau has been engaged for some time in a study of magnetic methods for the detection of flaws and defects in steel, with particular reference to wire hoisting ropes. The economic value of such a non-destructive method would be very great. Many investigations along this line have been made at the Bureau and elsewhere, but the uncertainty in the interpretation of results has hitherto been an obstacle in the way of practical application.

Experiments have recently been made at the Bureau to discover the cause of this uncertainty, and a method of eliminating it. It has been found that the greatest source of difficulty is the effect of variations in internal stress within the specimen. Such variations give rise to large differences in magnetic permeability, which produce effects similar to and often greater in magnitude than those caused by the flaws in the material. The results of recent experiments show that by the use of higher values of magnetizing force than have heretofore been employed, the effect of internal stress is greatly reduced without a corresponding reduction in the effect of flaws. It thus appears that one of the greatest difficulties in the way of practical application of this method has now been overcome. The experiments are being continued to determine whether or not sufficiently accurate interpretation of the results of magnetic exploration can be made to permit of its use as a practical inspection method.

Research in Electroplating

Satisfactory progress is being made in the study of nickel electroplating. During the past month solutions of known composition have been installed in two local electrotyping plants and are being kept under close supervision and observation in order to determne whether conclusions reached in the laboratory experiments can be confirmed in actual practice. The Bureau made a preliminary report of the results thus far obtained in this investigation at a meeting of the International Association of Electrotypers held at Rochester on April 17 and 18.

The results so far obtained in the study of the protective value of nickel plating upon iron and steel are being assembled in order to determine whether they are now ready for publication or whether further confirmatory tests will be required.

Satisfactory progress is being made in the application of chromium plating at the Bureau of Engraving and Printing, although the actual service results are not yet available.

In connection with the work of the Sub-Committee of the Federal Specification Board Upon Silver Plating, experiments are being made to determine

*Communicated by the Director of the Bureau of Standards, Dr. G. K. Burgess.

the accuracy of the usual method of stripping silver from silver plated articles in order to determine the weight of silver present.

A study of the operation of zinc plating solutions will shortly be undertaken.

Measurements on the Thermal Expansion of Fused Silica

The Bureau has completed measurements on the thermal expansion of representative samples of fused silica (fused quartz) between minus 125 degrees Cent. and plus 1000 degrees Cent. The specimens were furnished by commercial companies. This research was undertaken for the purpose of obtaining data on the thermal expansion of fused silica for use in thermostats, clock pendulums, length standards, pyrometers, gas sampling devices, acid resisting articles, insulating and temperature resisting devices, etc.

The expansion curves show very interesting results at low temperatures. For each sample of fused silica, a critical temperature (or minimum length) was found. On heating above this temperature the material expands, but on cooling below this temperature, expansion (instead of contraction, as might be expected) also takes place. In other words, the coefficients of expansion are positive above the critical temperature and negative below this temperature. From a consideration of all available results relating to the critical temperature, or minimum length of fused silica, 80 degrees Cent. may be taken as a representative value for the critical temperature of this material. The results at high temperatures are now being studied.

A manuscript giving the results of this investigaton is being prepared for publication. This publication will include a review of available information obtained by previous observers on the thermal expansion of fused silica, as well as a detailed description of the apparatus and methods of measurement required for the accurate determination of such minute values of the coefficient.

Thermal Expansion of Aluminum and Various Important Aluminum Alloys

Scientific Paper, No. 497, copies of which can now be obtained from the Superintendent of Documents, gives data on the thermal expansion of four samples of aluminum and 51 samples of important aluminum alloys. The preparation, chemical composition, heat treatment, etc., are included. Most of the specimens were examined in a range from room temperature to about 500 degrees Cent. Typical expansion curves of the various groups of samples are shown and discussed. In some cases, the data on expansion were compared with the equilibrium diagrams of binary alloys. After the expansion tests, the changes in length from the original lengths were determined.

A description of the apparatus used in this research and a review of the available information obtained by previous observers on the thermal expansion of aluminum and some of its alloys, are given.

The paper closes with a table showing the average coefficients of ex-

pansion of the materials investigated over several temperature ranges. For values of individual samples reference should be made to the proper section of the text.

Melting and Working Platinum

During the past 30 months approximately $16,000 worth of platinum has been melted and worked down to various sizes of wire at the Bureau of Standards. This wire has been used for heating coils, thermocouples, resistance thermometers, and other parts of scientific instruments in which platinum is indispensable. A large proportion of this amount of platinum has been especially purified metal. Some of it has been old heating coils and thermocouples purified, remelted, and reworked. The loss of metal in the processes of melting and working this amount of platinum has been equivalent only to about $200.

Since the needs of the Bureau for material of the highest purity are very exacting, it has been necessary to develop methods for purification, for remelting and working without contamination, as well as improved nondestructive methods of testing for purity. All this has been accomplished and the platinum thus melted and worked at the Bureau meets the most exacting requirements of research work. The purest platinum the Bureau has tested has been prepared in its own laboratories.

Arc Spectra of the Platinum Metals

The seventh paper in a series dealing with investigation on the platinum metals has recently been issued. This is Scientific Paper No. 499 of the Bureau of Standards, and is concerned with arc spectra of the platinum metals in the region from 4500 to 9000 A.

The previous papers have mentioned the use of the spectrograph to follow the progress of chemical separation of the metals of the platinum group. When materials approximating spectroscopic purity were prepared in the Bureau, an investigation of the arc spectra was undertaken primarily for the purpose of securing data in the red and adjacent infra-red regions where no data on the emission spectra of the platinum metals existed. Specially sensitized photographic plates and large diffraction gratings were employed to record the spectra, and many hundreds of new lines were measured in the yellow, orange, red and infra-red regions. Comparisons with previous observations in the regions common to the old and new measurements showed that the former were incomplete. This led to an extension of the work to shorter waves, thus including almost all the visible spectrum, and made it possible to carry out a more extensive comparison of the spectroscopic purity of the materials used by the different observers. New values of wave lengths and estimate intensities are given in 6 tables, as follows: 1,260 lines for ruthenium (4498.16 to 8867.84 A), 572 lines for rhodium (4503.80 to 8615.23 A), 172 lines for palladium (4497.66 to 9234.02 A), 942 lines for

(*Continued on Page 665*)

The Question Box

A Column Devoted to the Asking, Answering and Discussing of Practical Questions in Heat Treatment — Members Submitting Answers and Discussions Are Requested To Refer to Serial Numbers of Questions

NEW QUESTIONS

QUESTION NO. 151. *What effect does the temperature of an oil-quenching bath have upon the hardness of a piece of steel quenched into it from the proper hardening temperature?*

QUESTION NO. 152. *Is manganese up to 1.50 per cent detrimental in a steel to be used for carburizing purposes? How does the high manganese content affect the final product?*

QUESTION NO. 153. *What is meant by acid and basic steel?*

QUESTION NO. 154. *What are the advantages of nickel steel versus chromium-nickel steel for carburizing?*

ANSWERS TO QUESTIONS

QUESTION NO. 134. *What are the usual feeds and speeds used in machining both carbon and alloy automotive steels, when using high speed steel cutting tools?*

QUESTION NO. 137. *What is the mechanism of the iodine etch for the deep etching of steel?*

QUESTION NO. 138. *Is the electrolytic pickling process being used to show up defects in steel bars? If so, how does it compare with the regular pickling processes?*

QUESTION NO. 142. *What is the consensus of opinion of the cause of blisters in low and high grade steels sheets?*

QUESTION NO. 143. *How can these blisters be eliminated?*

QUESTION NO. 144. *Why do many chromium-nickel steels show a laminated structure when viewed under the microscope?*

ANSWER. By F. T. Sisco, metallurgst, Air Service, War Department, McCook Field, Dayton, Ohio.

By laminated structure the question probably refers to the familiar

banded structure characteristic of many low carbon nickel and chromium nickel steels and found occasionally in low carbon steels. It is due to segregated ferrite. The true cause is unknown, but the consensus of opinion is that it is caused by the elongation in rolling or forging of a peculiar crystallization condition present in the original ingot.

Banded ferrite is sometimes accompanied by segregated phosphorus and often by silicate and manganese sulphide inclusions. Some authorities have stated that banded structure is caused by phosphorus segregation and a few have claimed that it is due to segregation of non-metallic inclusions. However, bands of ferrite have been observed when inclusions were absent and when the phosphorus content in the steel was less than 0.025 per cent. Probably the banded structure is the original defect and the segregation of the ferrite into these bands is responsible for the segregation of the inclusions or phosphorus into this area.

QUESTION NO. 147. *Is it desirable or necessary to periodically anneal the chains used on cranes? If so, why?*

QUESTION NO. 148. *What is the relative proportion of basic open hearth and acid open hearth steel being produced at present, and is there a trend toward increased relative production of either?*

QUESTION NO. 149. *Do plates of basic open hearth steel ever have a higher base rate than acid open hearth steel?*

QUESTION NO. 150. *Is it possible to determine by means of test or examination whether a given piece of steel has been made by Bessemer, open hearth, or electric furnace process?*

ANSWER. By F. T. Sisco, metallurgist, Air Service, War Department, McCook Field, Dayton, Ohio.

There is no rapid test whereby Bessemer, open hearth, or electric steels can be definitely differentiated. Chemical analysis will tell whether a steel is Bessemer or open hearth. Most Bessemer steels contain between 0.075 and 0.120 per cent phosphorus, acid open hearth steels between 0.035 and 0.065 per cent phosphorus, and basic open hearth steels generally have a phosphorus content below 0.040 per cent and often below 0.030 per cent. Basic electric steels are usually low in phosphorus, and sulphur as well; ordinarily these elements are both below 0.030 per cent.

A rapid test used by the writer to differentiate roughly between the steels is as follows: Take drillings or millings from the steels to be tested. Sift the drillings through a 20-mesh sieve, retaining the portion which goes through 20-mesh, but does not pass through 40-mesh. Weigh approximately 5 grams of each into a 400 cubic centimeter beaker. Add 100 cubic centi-

meters of dilute hydrochloric acid (1 part acid, 1 part water) to each and place on a hot plate where the temperature will be uniform for all samples. Low carbon Bessemer steel will dissolve completely in 5 to 10 minutes, basic open hearth in 12 to 16 minutes, basic electric steel will take 25 to 30 minutes, and crucible steel about the same length of time. In order to use this test, the steels examined must have practically the same carbon and manganese content, and alloys must be absent. It is very important that the steels be in the same physical condition, annealed or normalized. The test works very well on samples of hot-rolled bars which have not been annealed but which have been cooled normally from rolling temperature. Too much reliance should not be placed on this test, but in general it is consistent and sufficiently reliable for ordinary purposes. The test is based on the rate of solution depending upon the denseness of the steel. Crucible and electric steel being most dense will dissolve slower, basic open hearth more rapidly, and Bessemer being oxidized most in refining will dissolve most rapidly.

NOTES FROM THE U. S. BUREAU OF STANDARDS

(*Continued from Page 661*)

osmium (4500.74 to 8644.8 A), 605 lines for iridium (4500.97 to 8426.11 A), and 239 lines of platinum (4498.75 to 8762.48 A).

The wave lengths were measured relative to the secondary standards in the spectrum of the iron arc, and each value is, in general, the mean of from two to ten determinations. The probable error of these values rarely exceeds one one-hundredth of an Angstrom unit. Six short tables giving lines ascribed to platinum metals by other observers, but not visible on the new spectrograms are subjoined to the major tables, and most of these lines are identified as impurities in the materials at the disposal of the earlier observers. Intercomparison of the results of the new measurements indicate that the metals used in this investigation were exceptionally pure, since even the most intense lines characteristic of each particular element rarely, if ever, appeared in the spectra of the other elements.

Copies of this paper may be obtained from the Suprintendent of Documents, Government Printing Office.

Reviews of Recent Patents

By
NELSON LITTELL, Patent Attorney
110 E. 42nd St., New York City
Member of A. S. S. T.

1,525,502, Method of Treating Metal Articles, William H. Graves, Jr., of Detroit, Michigan, assignor to Packard Motor Car Company, of Detroit, Michigan, a corporation of Michigan.

This patent relates to a method of cleaning and removing scale from hardened steel articles without injuring the articles or materially changing the physical properties thereof.

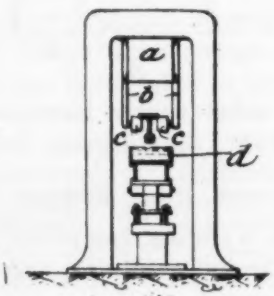
According to the inventor, it has heretofore been the practice, in hardening gears such as are used in the transmission or gear box of an automobile to heat the gears to a temperature around 1500 degrees Fahr. (815 degrees Cent.) and then quench in oil, which produces a scale on the surface of the article, that has usually been removed by rapidly revolving wire brushes, or by means of a file, or by scraping off the scale. The use of an electrically operated acid bath has heretofore been found objectionable because it changes the physical properties of the gears by reducing their strength or ductility. The present inventor proposes the use of an electrically operated acid bath without adversely affecting the physical properties of the articles, by first heating to the critical point, then quenching in oil, then heating to a lesser degree,—around 700 degrees Fahr. (371 degrees Cent.) to temper the gear, then cooling, and after washing in an alkaline solution, to remove the oil, and subjecting the gears to the action of an electrically operated acid bath, composed preferably of nine parts of water and one part of acid, the acid consisting of two parts of muriatic acid and one part of commercial sulphuric acid. The articles under treatment are connected as the cathode, and a series of carbon plates is used as an anode, and when loaded the acid tank is operated with five volts. By this process the articles may be cleaned economically without adversely affecting their physical properties.

1,526,513, Process and Apparatus for the Thermic Treatment of Steels and in General of All Other Alloys Susceptible of Hardening, Louis Francois Joseph Claude Antoine Thibaudier and Henry Viteaus, of Paris, France.

This patent relates to a process and apparatus for heat treating metal parts, whereby the quenching after the hardening operation is stopped at a high enough point to permit the reheating of the article from the latent heat therein, so that a second heating or annealing is not necessary.

The inventors point out that the ordinary method of arresting the hardening of the article before the article has become entirely cooled or of

quenching in a limited volume of liquid has the defect in the first case, that the stopping of the quenching operation at the correct temperature is usually very difficult under ordinary shop practice, and in the second case, the limited volume of cooling fluid quickly becomes heated and full cooling efficiency of the same is not realized, also, the formation of steam and air bubbles separating the bath from the piece causes nonuniform heating. The inventors therefore propose to correct this defect in the use of the one heating, hardening and annealing operation by cooling with a series of short immersions in a limited quantity of liquid. By immersing the heated article a number of times of short duration, they are able



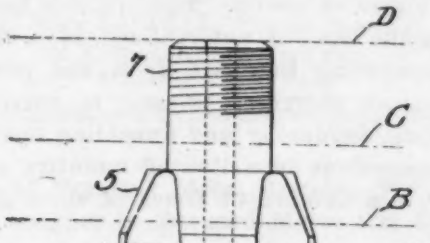
to check the cooling at the desired point and the series of immersions and emersions give sufficient agitation to the bath to permit uniform cooling of the articles.

In the illustrating figure a steel rail is suspended head down from the support and the cooling bath is rapidly raised and lowered to immerse and emerse the head by the plungers supporting the same.

1,526,894, Method of Heat-Treating Cutting Tools, Arthur E. Bellis, of New Haven, Connecticut, assignor to Bellis Heat Treating Company, of Branford, Connecticut, a corporation of Connecticut.

This patent relates to a method of heat treating cutting tools, whereby better control of the hardening operation may be secured, and the tip of the tool hardened while the shank and the portions back of the tip may be treated to retain a high degree of toughness and resistance to tensile strains. The lead baths and muffle furnaces heretofore used in the heat treating of cutting tools have not been entirely satisfactory, because the high viscosity of the lead and the nonuniformity of the furnace lead to unequal heating of the article. The inventor uses a salt bath consisting preferably of a eutectic mixture of sodium chloride and sodium carbonate, or other salts, which has a high volatilization point, and first inserts the cutting points of the tool into the bath and later slowly immerses the portions back of the cutting points, so that the cutting points are subjected to the heat for a longer period, and are consequently heated to a higher degree than the shank of the tool, giving a greater hardness to the point and greater strength and toughness to the shank. The low viscosity of the salt bath permits rapid heating and uniform temperature in all parts of the bath,

so that uniform heating of the tool is realized. In the figure shown, the points 6 of the cutting tool are immersed first, then the shank 5, and the pilot 7, in the successive zones, as indicated by A, B, C and D. If desired,



the pilot end 7 may be subsequently immersed in the salt bath at approximately 700 degrees Fahr. (371 degrees Cent.) to temper it.

1,527,013, Luting Compound, Hugh Rodman, of Oakmont, Pennsylvania.

This patent describes a luting compound for case hardening boxes, which reduces and prevents the oxidation and scaling of the boxes along the edges where they are sealed.

The inventor states that it is his belief that the chemical action of the luting compound used rather than the action of the furnace gases, promotes this rapid oxidation and scaling of the annealing boxes around the edges. To correct this, he uses as his luting compound a small percentage of basic material, such as hydrated lime or lime carbonate and the ordinary fire clay used for luting. He mixes this to a suitable consistency with water, and seals the box as in ordinary practice. For ordinary fire clay the addition of 10 per cent by weight of powdered limestone is sufficient to neutralize its tendency to cause scabbing. To promote binding of the fire clay 5 per cent by volume of ordinary wheat flour may be used.

1,527,418, Process and Material for Treating Metal, Albert H. Ackerman, of Chicago, Illinois, assignor to William H. Colvin, of Chicago, Illinois.

This patent describes a new energizer for case hardening compounds which will generate carbon monoxide gas at a lower temperature, and a process of using the new energizer.

The energizer used is natural phosphate rock, giving an analysis substantially that of fossilized bone. This material, after being mined, is dried at 240 degrees Fahr., crushed into a granular form, and dried again at 300 degrees Fahr. The material is then mixed as follows:

	Per Cent.
Coke	25
Charcoal	35
Fossilized bone energizer	40

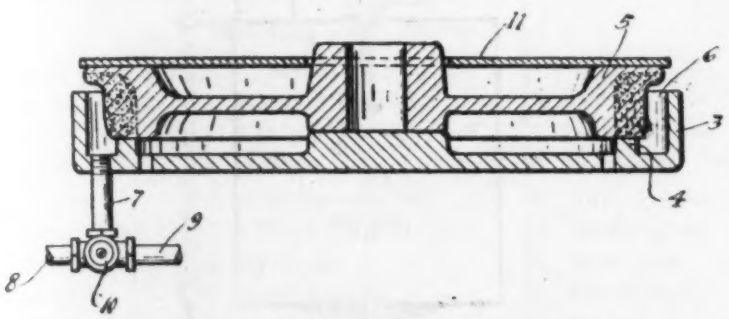
The new energizer produces the desired energizing gases at temperatures of 1200 to 1400 degrees Fahr., (649-760 degrees Cent.) as compared

with the usual temperatures of 1650 to 1800 degrees Fahr. (898-982 degrees Cent.), and may be used a greater number of times than the old energizer before exhaustion.

The patent claims the energizer itself in the case hardening compound, and also a new process of case hardening wherein the case hardening mixture containing the rock phosphate is heated to a temperature not exceeding 1400 degrees Fahr. (760 degrees Cent.)

1,527,418, **Method and Apparatus for Hardening the Surfaces of Car Wheels, Elmyr A. Laughlin, of Oregon, Illinois, assignor of One-Half to Himself and One-Half to Joshua R. H. Potts, of Chicago, Illinois.**

This patent describes a method and apparatus for hardening the surfaces of car wheels, which comprises a trough-like receptacle 3 having a flange 4 adapted to support the inner edge of the car wheel 5 and provided



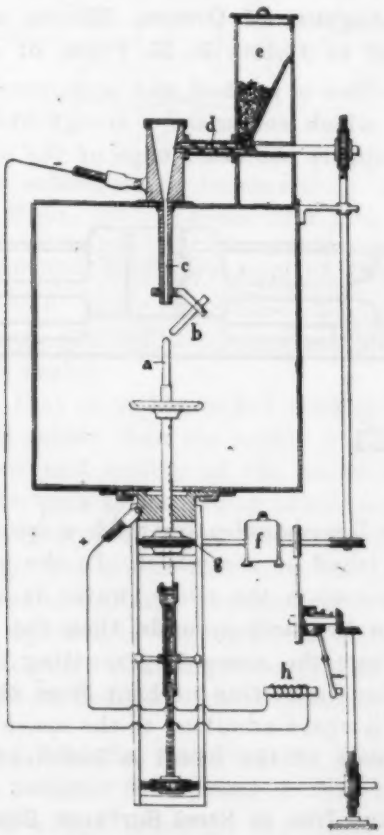
with a water conduit 7 communicating with a space 6 between the rim of the vessel 3 and the tread of the wheel. In the use of the apparatus the heated wheel is placed upon the rib 4, water is admitted to the space 6 for a period of fifteen to thirty seconds, then the flow of water is discontinued and drained from the space 6, permitting the tread portion of the wheel to reheat by the conduction of heat from the interior of the wheel, whereupon the water is again admitted to the space 6 and permitted to flow therefrom until the body of the wheel is sufficiently cooled.

1,527,538, **Calorizing Iron or Steel Surfaces, Samuel F. Cox, of Wilkinsburg, Pennsylvania, assignor to The Calorizing Company, of Pittsburgh, Pennsylvania, a corporation of Delaware.**

This patent states that it has been found in the calorizing of iron and steel articles, that the lower the carbon content of the articles, the better the penetration of the calorizing material. The inventor therefore proposes, instead of limiting the use of calorized material to articles of low carbon content, to decarbonize the surface of the article to be treated, to a depth approximately that desired for the penetration of the calorizing material (aluminum), and then to carry on the calorizing operation. The surface of the article may be decarbonized by heating in contact with metal scale, or by heating in a furnace with free contact of air, or by passing air over the surfaces of the articles at high velocity. After being decarbonized, the calorizing process is carried out in the usual way.

1,529,943, Process for Obtaining Metals Having a High Melting Point, such as Tungsten, Antoine Charles Constantin Marie Philippe Brunot de Rouvre, of Paris, France, assignor to Societe Anonyme des Brevets Berthet, of Paris, France.

This patent describes a process of producing metallic tungsten by fusion, which comprises feeding tungsten powder or an oxygenated compound of tungsten from the hopper e by means of the screw conveyor d into the channel c of the upper electrode b and permitting it to drop from the



end of the channel c upon the electrode a, where it is fused by the arc between electrodes a and b.

The electrode a is rotated and gradually drawn away from the electrode b as the material is built up by means of the worm wheel g, rotated through the motor f. The chamber in which the electrodes a and b are located is preferably filled with hydrogen or hydrogen and nitrogen, or other gases having non-oxidizing properties. When a sufficient amount of the fused metallic material has been formed, it may be hammered, or drawn, or otherwise formed into filaments of electric wire or for other purposes.

News of the Chapters

STANDING OF THE CHAPTERS

IN the April issue of TRANSACTIONS appeared the relative standing of the 29 chapters of the Society as of February 1, 1925, and as of March 1, 1925. The tabulation which appears below shows the relative membership standing of the chapters on April 1, 1925. For the convenience of ready comparison, the standing as of March 1, 1925, is included.

Thirteen chapters made a gain in members, nine stood still, and seven lost. There were a total of 97 new members, added to 9 reinstated, making a total of 106 acquisitions for the month. There must, however, be subtracted from this number, 41 dropped for non-payment of dues, and 19 resigned, which makes a net gain for the month of 46.

Standing as of March 1

GROUP I	GROUP II	GROUP III
1. CLEVELAND (283)	1. Hartford (128)	1. Tri City (61)
2. Detroit (278)	2. Lehigh Valley (116)	2. Los Angeles (56)
3. Pittsburgh (272)	3. Golden Gate (103)	3. Rochester (55)
4. Chicago (270)	4. Milwaukee (75)	4. New Haven (52)
5. Philadelphia (253)	5. CINCINNATI (72)	5. Washington (50)
6. Boston (223)	6. Syracuse	6. Worcester
7. New York (207)	7. Indianapolis	7. Schenectady
	8. Buffalo	8. Rockford
	9. St. Louis	9. Providence
	10. North West	10. South Bend
		11. Springfield
		12. Toronto

Standing as of April 1

I	II	III
1. Cleveland (295)	1. Hartford (127)	1. Tri City (66)
2. Detroit (288)	2. Lehigh Valley (111)	2. ROCHESTER (62)
3. Pittsburgh (272)	3. Golden Gate (102)	3. Los Angeles (56)
4. Chicago (266)	4. Milwaukee (74)	4. New Haven (52)
5. Philadelphia (251)	5. Cincinnati (73)	5. Washington (50)
6. Boston (228)	6. Syracuse	6. Worcester
7. New York (206)	7. Indianapolis	7. Schenectady
	8. St. Louis	8. Rockford
	9. Buffalo	9. Providence
	10. North West	10. SPRINGFIELD
		11. South Bend
		12. Toronto

In Group I, Cleveland maintains the lead for March with 295 members. Detroit is second with 288. The other chapters remain in the same relative position as last month.

In Group II, St. Louis shows a gain, advancing to 8th position.

In Group III, Rochester advances from 3rd place to 2nd, going ahead of Los Angeles, but four short of Tri City in first position. Rochester showed a net gain of 7 new members for the month, while Tri City kept ahead with 6 new members. Both of these chapters are still busy, and we may look for some interesting developments during the coming month. Springfield moves from 11th to 10th place.

BOSTON CHAPTER

THE Boston chapter of the A. S. S. T. held its regular monthly meeting March 19, 1925, in the Walker Memorial Building of Massachusetts Institute of Technology.

The usual excellent supper was served at 6:30 with an attendance of approximately seventy-five members and guests.

Following the supper a very interesting talk entitled "Heat Treating Equipment" was presented by Mr. W. S. Bidle, National President of our Society and president of the W. S. Bidle Co., Cleveland, Ohio. Mr. Bidle used the blackboard to illustrate some of the points regarding equipment and to show figures comparing costs between various fuels. Mr. Bidle's talk was extremely interesting and promoted a very interesting discussion as it was the type of a talk which is more needed at a meeting since it was the thoughts of a practical man not interested in any particular type of equipment but more interested in obtaining the most dollars in return from those invested. He showed the absolute necessity of any concern contemplating the purchase of equipment, approaching the problem from an engineering standpoint and working out a definite engineering report, showing the benefits derived from any particular fuel or equipment depending upon the exact requirements and conditions of the plant.

Previous to Mr. Bidle's talk, our National Secretary, Mr. W. H. Eisenman spoke on our Society. Bill had some interesting information on the developments of the Society business and suggestions as to how to improve the local chapter.

G. C. Davis

Meeting: April 23, Massachusetts Institute of Technology.

Subject: "Magnetic Testing,"—R. L. Sanford, chief of magnetic laboratory, Bureau of Standards.

Meeting to be reported in the next issue of TRANSACTIONS.

BUFFALO CHAPTER

On March 30, 1925, the Buffalo chapter of the Society held a meeting at Hotel Buffalo. At 8:45 p. m., the meeting was opened for discussion due to the late arrival of the speaker, Mr. Hanks of the Taylor-Wharton Iron and

Steel Company. The following is a general outline of the address: History of manganese steel; chemical and physical properties; heat treatment and pictures showing the application of manganese steel. An interesting discussion followed the presentation. The chemical analysis of the steel discussed is as follows:

	Per cent
Carbon	1.00 to 1.40
Manganese	12.00 to 14.00
Sulphur	0.05
Phosphorus	0.10
Silicon	1.00

This material is very brittle as cast but when heated to 1940 degrees Fahr., and quenched in water, the following physical properties can be obtained:

Tensile strength 70,000-100,000 pounds per square inch
Yield point 30,000- 40,000 pounds per square inch
Elongation in 2 inch-15 per cent
Brinell 185-200

When cold-worked, a Brinell of 450-500 can be obtained. A tempering temperature of 950 degrees Fahr., after quenching from 1940 degrees Fahr., produces a very hard and brittle steel. The cold work at the surface of manganese steel imparts a very hard surface.

The meeting adjourned at 10:45 p. m. About 40 members and guests were present.

B. Clements.

CHICAGO CHAPTER

Following the usual practice of the Chicago chapter, another double program was held April 9, 1925, at the City Club. The half-hour immediately following supper (7:00 to 7:30), during which coffee was served, Don B. McCloud, associated with Keith Dunham, gave a very interesting lecture and demonstration on "The Production of Oxygen by the Liquefaction Process".

Special demonstrations with liquid oxygen were performed, such as frying eggs on a cake of ice, making marbles out of cranberries, and operating a miniature steam engine having at the same time frost on the boiler walls. These and other experiments, such as are carried on in physics laboratories, were dexterously performed.

Mr. McCloud's principal message to his listeners concerned the proper handling of liquid oxygen and a detailed account of its scope and activity in the oxygen manufacturing plant. Interesting stereopticon slides, showing the manufacture of liquid gas in a commercial plant, were shown.

The metallurgical talk of the evening was by T. H. Nelson, consulting metallurgist of the United Alloy Steel Corporation. Mr. Nelson was born in Sheffield, England, in 1886, educated at Sheffield University and com-

menced work in the plant of Thomas Firth & Sons, Ltd., Sheffield. Among the prominent metallurgical positions Mr. Nelson has held have been with the following companies: Darwin & Milner, Sheffield; Simonds Mfg. Company, Fitchburg, Mass.; Henry Disston & Sons; and the United Alloy Steel Corporation. Mr. Nelson is a member of the following societies: American Iron & Steel Institute, American Society of Testing Materials, American Society for Steel Treating, British Iron & Steel Institute, and the Sheffield Society of Engineers & Metallurgists.

Mr. Nelson delivered an exceptionally fine talk on the fundamentals of the so-called "Stainless Steels". His talk was particularly complete in that stainless steel had its inception at the time he was associated with the great British metallurgist, Harry Brearley.

The principal use for stainless steel is in the manufacture of pump shafts, ammonia tank machinery, and in connection with all other liquids having a corrosive action upon ordinary steels.

Mr. Nelson predicts that in the near future, these types of steel will be used in steel structural work such as bridges, etc. A great many hitherto unrealized points were brought out. He spoke of one misconception of stainless steels, that being, that most people are under the impression that stainless steel comes from the mill in its finished condition. On the contrary, it has to be ground and polished before it possesses its characteristic quality.

Mr. Nelson's talk brought on a very interesting and lively discussion of the subject of stainless steels. This discussion demonstrated the great interest metallurgists are now showing in this important subject. It probably is one of the most interesting subjects in all metallurgy.

The May meeting of the Chicago chapter will be held in Ryerson Physics Laboratory of the University of Chicago. Doctor H. B. Lemon will talk on the "Constitution of Solids". His remarks will be illustrated by actual laboratory experiments that promise to be of extreme interest to the practical metallurgist. This is considered a rare opportunity. Those knowing of the phenomenal work of Doctor Lemon are looking forward to one of the most important meetings of the year.

CINCINNATI CHAPTER

Meeting: April 9, University of Cincinnati.

Subject: "Heat Treated Materials in Aircraft Structure and Aircraft Power Plant,"—J. B. Johnson, chief of materials section, Engineering Division, Army Air Service, McCook Field, Dayton, Ohio.

Report of meeting not received.

CLEVELAND CHAPTER

The regular April meeting of Cleveland chapter of the A. S. S. T. was held on Friday evening, April 17, 1925, at 8:00 p. m. in the rooms of the Cleveland Engineering Society, Hotel Winton.

Jerome Strauss, material engineer, U. S. Naval Gun Factory, Washington,

D. C., presented a paper on "High Speed Steel—A Consumer's Viewpoint." Mr. Strauss not only summarized some of the previous work on high speed steel, which he had done in collaboration with H. J. French of the Bureau of Standards, but also mentioned several interesting points which had been investigated since the appearance of their published papers on lathe tool tests, etc.

As an introduction to his subject, Mr. Strauss stated that high speed steel is really quite similar to many other tool steels in its characteristics; the factors governing grain growth, for example, are about the same.

The manufacturer of high speed steel, whether he uses the electric or crucible process, is able to control the composition. He can also control the melting practice, and what is even more important, he can control the pouring practice. The initial forging operations, the rate of reduction in forging and the final annealing are also factors of great importance.

In speaking of the use of high speed steel, Mr. Strauss called attention to the fact that re-forging is sometimes a rather delicate operation, especially if upsetting is necessary.

In referring to the extensive work on lathe tool tests, the speaker discussed briefly the four different types of steel which had been tested. He also compared the Taylor test with the so-called "breakdown test" and explained his preference for the latter. When the Taylor test is used, the operator or investigator has to be careful to interpret his results, to find out what they really mean. It is not so difficult to get consistent results with the Taylor test, but on this account the results are likely to be misleading. In connection with the modified breakdown test which Mr. Strauss and his associates had adopted, they had worked out an exceedingly useful formula by means of which they could determine the conditions of cutting for a given life of tool. For example, the cutting speed at which failure will occur in one hour or in any other given time can be predicted after a preliminary test has been run.

Another subject discussed was "flaky fractures." These can be prevented by an annealing at about 1650 degrees Fahr. previous to re-hardening.

The thermal analysis of high speed steel was also briefly covered.

In speaking of dimensional changes after heat treatment, Mr. Strauss said that a tempering at exactly the right temperature subsequent to the high heat treatment made it possible to bring back a tool to its original dimensions. One interesting point brought out by the speaker was that the effect of the tempering temperature used is almost negligible, as shown by the performance of the lathe tools. The only real value of tempering, according to Mr. Strauss, is to decrease brittleness. Another interesting point mentioned was that certain lathe tools tempered at 1300 degrees Fahr. lost only about 10 per cent cutting efficiency as compared with tools tempered at 1060 degrees Fahr.

A few of the applications of high speed steel in ordnance work were described and illustrated by lantern slides.

Segregation in large bars of high speed steel was also well illustrated by photomicrographs at both low and high magnifications. This segregation was said to be not necessarily injurious in lathe tools but produces brittleness in any tool like a milling cutter, which cuts intermittently.

In regard to the writing of specifications, emphasis was placed on the

consideration of the use to which the steel is to be put. The speaker urged a "gentlemen's agreement" between producer and consumer.

In his opinion, the producer of high speed steel still has plenty of opportunity to improve his product. Suggestions made were the casting of hollow ingots so as to allow quicker solidification, and second, the introduction of the alloying elements through reduction of the slag (in the electric process).

A number of other points not mentioned in this report were also touched upon, and an interesting discussion followed the presentation of the paper.

Dinner was served in the hotel dining room preceding this meeting. About 25 attended the dinner, and about 120 members and guests were present at the technical session. *A. S. Townsend.*

DETROIT CHAPTER

Meeting: April 20, General Motors Building.

Subject: "Practical Problems in the Heat Treatment of Steel,"—L. W. Heiser, Ford Motor Company and W. S. Bidle, national president of the A. S. S. T., and president of W. S. Bidle Company.

Meeting to be reported in the next issue of TRANSACTIONS.

GOLDEN GATE CHAPTER

The April 11 meeting of the Golden Gate chapter of the Society was held at the Engineers Club, San Francisco, in connection with the California Post of the Army Ordnance Association. Sixty-eight men sat down to dinner and there were a number of late arrivals. In view of the approaching May election, a nominating committee was selected consisting of Messrs. Pelle, Thurston and Moody, to draw up a ticket of officers and an executive committee, to be submitted to the chapter at the next meeting. Dr. Crook was named by the chairman as alternate. The first speaker of the evening was S. H. Edwards, whose subject, "Hardening, Drawing and Annealing," was No. 5 of the series of lectures on steel. Mr. Edwards illustrated his talk with an ingenious device, designed to demonstrate the physical results resulting from the application of temperatures in the process of hardening. Major M. L. Brett of the Ordnance Corporation, U. S. Army, followed with a description of the work that is being done by that branch of the service in co-ordinating the peace-time industries with possible war-time needs. This is a phase of the Army's activities that is little known by the general public and proved most interesting to the chapter. *D. Hanson Grubb.*

HARTFORD CHAPTER

On April 7 the Hartford chapter of A. S. S. T. held a joint meeting with the Hartford chapter of A. S. M. E. in the auditorium of the Hartford Electric Light Company.

The meeting was preceded by a dinner at the City Club attended by about thirty-five.

At the meeting, 32 A. S. S. T. members and 85 others heard a talk by W. R. Bean of the research department of the Eastern Malleable Iron Company,

Naugatuck, Conn. His remarks, accompanied by lantern slides, covered the production of malleable iron from the mine to the finished article, describing several methods used in melting and mixing the metal, touching on the necessity for castings of certain qualifications, method of annealing and testing. The point was brought out that through research in recent years it is now possible to obtain malleable iron of uniformly high physical properties in castings weighing from a fraction of an ounce up to one thousand pounds or more. Charts and micrographs were shown covering the malleablizing process.

Malleable iron has a wide field of use from its qualities of strength, ductility resistance to shock, resistance to corrosion and machinability together with the possibility of casting to intricate shapes. Many questions from the audience brought out additional points about this material and showed an active interest in the subject. A number of specimens on exhibit showed the extreme amount of bending and twisting which malleable iron castings will stand without breaking.

Edgar D. Lambert.

INDIANAPOLIS CHAPTER

The Indianapolis chapter of the Society had the pleasure of having W. S. Bidle, national president and W. H. Eisenman, national secretary of the A. S. S. T., as guests and speakers for the April 13 meeting. At 6:30 p. m., a dinner was served at Y. M. C. A., which was well attended. After a short business meeting, Mr. Bidle gave an interesting talk on the "Important Things in Heat Treating." The two things emphasized were the equipment and the operator. Mr. Bidle brought forth many interesting facts about experience and also data obtained from the experience of other companies. He also answered many questions which solved many difficulties experienced by the members and guests in attendance. Mr. Eisenman then entertained the boys for about twenty minutes with some interesting stories. He told the chapter the intentions of the Society for the coming year, about the Cleveland Convention in September and about the standing of the Society. This meeting was one of the most successful the Indianapolis chapter has had.

H. A. Maves.

LEHIGH VALLEY CHAPTER

The spring meeting of the Lehigh Valley chapter was held in conjunction with the Engineers' Club of the Lehigh Valley at the Exhibition Building of the Bethlehem Steel Company on Friday, April 3, 1925. The meeting was a symposium on welding, and consisted of demonstrations of all types of welding operations in the afternoon, followed by moving pictures, a buffet supper and technical papers. The concerns that took part in the demonstrations in the afternoon were—

Westinghouse Electric and Manufacturing Co.
Air Reduction Sales Company
General Electric Company
Oxweld Acetylene Company
H. Kleinhans Company
Metal and Thermit Corporation.

The following papers were presented in the evening:—

"Metallurgical Study of Arc Welded Joints in Mild Steel," by A. J. Bissel, Westinghouse Electric and Manufacturing Co.

"Economies to be Effected by Oxygen Purity," by J. J. Crowe, Air Reduction Sales Company.

"Welding of Iron and Steel," by D. H. De Yoe, General Electric Company.

"Effects of Torch Cutting," by E. E. Thum, Oxweld Acetylene Co.

"Thermit in the Steel Mills," by J. H. Deppeler, Metal and Thermit Corporation.

"Precision Welding," by S. W. Mann, of H. Kleinhans Co.

Two hundred and sixty-one people registered for the meeting, and there were a considerable number present who did not register. The interim between the demonstrations and the evening meeting was occupied by inspection of the Exhibition Building of the Bethlehem Steel Company, which contains samples of representative products of each of the different plants of the Bethlehem Steel Corporation. *B. F. Shepherd.*

LOS ANGELES CHAPTER

The Los Angeles chapter of the American Society for Steel Treating held a meeting on April 8 at the California Institute of Technology, Pasadena. The subject of the meeting was "Physical Testing." Prior to the meeting, Professor Sorenson, head of the department of electrical engineering, demonstrated the one million volt transformer and transmission of current as was perfected by their own method in their large electrical laboratory. The many phenomena surrounding such transmission, the producing of lightning, and the jumping of huge spark gaps, proved very astonishing to all present. The physical laboratory under the jurisdiction of Professor Heinrich was open to the members and actual methods of testing were demonstrated, using samples of steel both treated and untreated, as furnished by members of the chapter. Much credit is due to Professor Heinrich, Professor Clapp and their assistants, in scheduling this interesting meeting.

The following new officers were elected at this meeting: chairman, C. A. Stiles, Lacey Mfg. Co.; vice-chairman, Charles Drank, Axelson Machine Co.; secretary-treasurer, E. C. Black, Baker Iron Works; Executive Committee, W. H. Laury, Axelson Machine Co.; Wade Hampton, Hughes Tool Co.; W. C. Hartman, Union Tool Co.; and G. C. Nelson, Firth-Sterling Steel Company. *W. H. Laury.*

MILWAUKEE CHAPTER

On Monday, April 13, the Milwaukee chapter held its regular monthly meeting at the Hotel Blatz. Judging from the attendance and from the discussion which followed the illustrated talk by J. V. Emmons on "Machinability of Steel," the meeting was a success. The lecture was preceded by a dinner which was generously attended.

The date of the May meeting has not been definitely set but it will be addressed by Mr. Malm of the Lincoln Electric Company.

T. A. Moorman

NEW HAVEN CHAPTER

Meeting: April 23, Winchester Club House.

"Subject: "Heat Treating of Automobile Parts,"—J. M. Watson, metallurgical engineer, Hupp Motor Car Corporation, Detroit.

"Our Society,"—W. H. Eisenman, National Secretary of the A. S. S. T.

Meeting to be reported in the next issue.

NEW YORK CHAPTER

Meeting: April 17, Assembly Rooms of the Merchants' Association of New York, Woolworth Building.

Subject: "On the Nature of High Speed Steel,"—Dr. Carl Benedicks, director of the Metallographic Institute of Stockholm, Sweden.

Meeting to be reported in the next issue of TRANSACTIONS.

NORTHWEST CHAPTER

The Northwest chapter of the society held a well-attended meeting at the Manufacturers' Club of Minneapolis on April 14 at 8:00 p. m.

On this occasion J. V. Emmons of the Cleveland Twist Drill Company of Cleveland, Ohio, addressed the chapter on the "Machinability of Steel," illustrating his talk with some very interesting lantern slides. Mr. Emmons points out that the scleroscope, Brinell, Rockwell, and Keep drill tests for hardness were unable to solve difficulties encountered in the machining of tool steels. When the microscope was introduced it helped materially in solving the problems. With chemical analysis, hardness tests, and microscopic examination, most of the difficulties can be explained and remedied.

Mr. Emmons emphasized that the machinability of steel depends mainly on (1) the amount of carbide, and (2) the distribution and form of the carbide. If turning operations only are to be performed on tool steels, a granular pearlitic structure is most desirable, but this is a poor structure for milling work making the cutters clog and bind. If milling operations only are to be performed, a "compromise structure" is desired which consists of about one-half lamellar pearlite and one-half granular pearlite (spheroidal cementite). This structure will have a scleroscope hardness of about 40 and a Brinell hardness between 200-220. This "compromise structure" is produced by cooling the steel at a rate between that of normalizing and that of annealing.

This structure is best adapted for machined products where turning, cold swaging, milling, and wire drawing operations are all to be performed on the tool steel and where it is not advisable to heat treat differently for each operation. He also pointed out that steels with a large grain size are harder to machine and take a rougher finish than fine grained steels.

A decarburized surface skin or "bark" will form on tool steels during

the annealing treatment if air is allowed to come in contact with the steel. In removing this bark to prevent soft spots in hardening, this practically pure iron skin forms burs on the cutting tools which are hard to remove and cause a tearing of the surface being machined.

In the discussion following the lecture it was brought out that about 0.5 per cent chromium is desirable in tool steel in order to counteract the tendency of high carbon steels to partly malleablize in the annealing treatment. A steel partly malleablized can be readily detected by its dull sheen after machining.

At the close of the meeting Mr. Emmons was given a most hearty vote of thanks for his address. *R. L. Dowdell*

PHILADELPHIA CHAPTER

Meeting: April 24, Engineers' Club.

Subject: "Developments in Rustless Iron,"—T. H. Nelson, Wm. T. Bates & Son, Conshohocken, Pa.

"Heat Treating Methods at the Hupp Plant,"—J. M. Watson, Hupp Motor Car Corp., Detroit.

Meeting to be reported in the next issue of TRANSACTIONS.

PITTSBURGH CHAPTER

The Pittsburgh chapter held its April meeting on the evening of the 7th in the Assembly Room of the Fort Pitt Hotel.

The two motion pictures shown before the paper of the evening was given, were unusually interesting. These pictures were loaned to the chapter by the Westinghouse Electric and Manufacturing Company, and it was the first time that they had been shown in public. One entitled "Electrified Travelogue" showed many scenic views of mountainous country which is traversed by the giant electric locomotives manufactured by this company. The other picture, called, "White Coal," was a very instructive one which described the mammoth hydroelectric generators in use at Niagara Falls, N. Y., the method of operation and, finally, the various uses to which this electric current is put.

Vice-Chairman O. B. McMillen presided at a short business session and then welcomed J. P. Gill, metallurgist of the Vanadium Alloys Steel Company, who presented the paper of the evening.

Mr. Gill chose as his subject, "The Chemical Composition of Tool Steels." He prefaced his talk with a few remarks concerning standardization of chemical composition and the great number of brands of tool steel.

The first steel discussed was the straight carbon tool steel and he described the limits of the various elements found therein and the detrimental effect these elements would have if present in excess of these limits.

In describing the many kinds of non-deforming steels of the manganese types, the speaker explained that a small addition of vanadium results in a tougher steel and at the same time tended to prevent grain growth when overheated.

The next steel to be taken up was the low tungsten-high carbon steel which is of 1.00-2.00 per cent tungsten and 1.00-1.25 per cent carbon, and should not be confused with the 0.50 per cent carbon punch or chisel steel nor with the slightly higher carbon and from 2.00-5.00 per cent tungsten drawing die steel. Here again the addition of vanadium resulted in a tougher steel. A small addition of chromium was found to aid the solubility of the tungsten in this steel.

The hot working steels mentioned included one of about 0.40 per cent carbon, 10 per cent tungsten, 3.25 per cent chromium and 0.50 per cent vanadium, which is sometimes called semi-high-speed, 0.90 per cent carbon and 4 per cent chromium steel, and a low carbon, about 0.50 per cent, low alloy type. Oil hardening steel is generally used for this type of steel though air hardening steel is used in some cases.

The high speed steels described were many and varied, though, of course, the standard types such as the 18-4-1 and the 14-4-2 were considered at greater length.

This paper contained much information which is of interest to steel users as well as steel makers, it was well delivered and sincerely appreciated and enjoyed by an unusually large attendance. *H. A. Neeb, Jr.*

PROVIDENCE CHAPTER

Meeting: April 21, Brown University.

Subject: "Heat Treatment of Automobile Parts,"—J. M. Watson, metallurgist engineer, Hupp Motor Car Company of Detroit.

ROCHESTER CHAPTER

"The Manufacture of Sheet Steel," was the title of the paper read before the Rochester chapter of the American Society for Steel Treating by W. J. McArdle on April 13. Mr. McArdle is assistant sales manager of the Alleghany Steel Company and has specialized in the development and distribution of sheet steels for electrical purposes for many years. He described the complete cycle of operations employed in the fabrication of sheet steels. The selection of steel scrap, the types of melting furnaces used, casting, rolling and the various heat treatments given the steel were all very thoroughly and interestingly explained. The discussion of the process of deoxidizing electric sheet steel to form a heavy scale which acts as an insulator, thus decreasing eddy current losses in electrical units, together with the method of using chilled, highly polished cast iron rolls which impart the flawless surface to automobile body sheet steel, proved highly instructive. The North East Electric Company's film entitled, "The Electric Equipment of the Motor Car," that preceded the speaker was well worth seeing.

F. T. Flaherty.

ROCKFORD CHAPTER

No report received.

SCHENECTADY CHAPTER

A very interesting meeting of the Schenectady chapter was held on March 24 in the Rose Room of the Twentieth Century Lunch Room. Marcus A. Grossmann, metallurgical engineer of the United Alloy Steel Corporation of Canton, Ohio, talked to us on "Manufacturing Problems in Alloy Steels." The talk was illustrated with lantern slides.

The Schenectady chapter wishes to extend a hearty invitation to all to attend the Spring Sectional meeting, which is going to be held here on May 28, 29, and 30. Arrangements have been made to visit the plants of the Ludlum Steel Company at Watervliet, the General Electric Company and American Locomotive Company at Schenectady. A very interesting program of papers is being prepared, which will prove very instructive to those attending.

James Taylor.

SOUTH BEND CHAPTER

Meeting: April 28, Museum, South Bend Y. M. C. A.
Subject: "Problems in Heavy Forging,"—Wm. Finkl.
No report received.

SPRINGFIELD CHAPTER

Meeting: April 30, Chamber of Commerce Rooms.

Annual get together meeting for purpose of electing officers for the ensuing year. Informal discussion of heat treating problems by members.

Meeting to be reported in next issue of TRANSACTIONS.

ST. LOUIS CHAPTER

The St. Louis chapter held their March meeting at the American Annex Hotel on Monday night, March 30th. Both the dinner and meeting were very well attended and a large proportion of the membership were on hand to meet the National officers.

The program consisted of a very instructive paper by W. S. Bidle, National President, on "Experiences in Heat Treating," and Mr. Bidle dwelt at length on the most economical equipment for a small commercial plant.

National Secretary, W. H. Eisenman spoke of the progress of the Society and advised the St. Louis members of the exact status of "Their Society." He reported that the sectional meeting at Schenectady was quite popular and assured his listeners that the Cleveland Convention would surpass all others.

A. E. Tarr, Hump Furnace Division, Leeds & Northrup Company, Chicago, was the speaker at the April meeting of the St. Louis Chapter, which was held on Monday, April 27, at the American Annex Hotel.

Mr. Tarr's talk was illustrated with numerous lantern slides and dealt with the principle and uses of the Hump furnace and "Hump Curve".

Fifteen members of the Senior Class in Metallurgy, Missouri School of Mines, Rolla, attended the meeting which brought the attendance up to over fifty.

The chairman announced that the Chapter membership had increased from 30 to 55 in the past year, showing that the heat treaters in St. Louis and vicinity are backing the Society. A nominating committee composed of Messrs. L. T. Clark, E. C. Cooper, and C. G. Werscheid were appointed to offer nominations for officers at the May Meeting. The program for this meeting will consist of motion pictures on the making of Armco ingot iron and will be held Friday, May 15th.

F. G. White.

SYRACUSE CHAPTER

On Monday, April 20, the Syracuse chapter of the American Society for Steel Treating held a rousing meeting with 200 members and guests present. Walter Bolton, chairman of the Program Committee has gained an enviable reputation for the excellent and interesting meetings scheduled the past season and the April meeting with J. M. Watson of Hupp and his moving pictures of their Jackson heat treating plant proved equally successful. The meeting was held in the recreation room of the New Process Gear Company's plant. "Bill" McNally, the genial and efficient metallurgist of the New Process, and his able assistant, G. A. Gilger, secretary of the chapter, were excellent hosts and paid particular attention to even the smallest details so that every one present felt a cordial welcome. A fine five-course dinner was served to 150 at 6:30 p. m. The music of the New Process String Quartette together with the group singing and noisy favors and hats, gave a jovial atmosphere to a jolly gathering. After dinner, an inspection of the plant took place under the direction of C. S. Grannis, works manager. Great interest was manifested in the heat treating department which was pronounced very efficient and up to the minute. After the plant inspection the members gathered again in the recreation room where Chairman Sam Spalding called the meeting to order. National Secretary W. H. Eiseman was present and spoke briefly on the services and objects of the A. S. S. T. Mr. Watson then presented the principal paper of the evening, explaining the films as shown and giving details of methods of heat treating used in the Hupp plant. At the close a vote of thanks was authorized to Mr. Watson; and also to the officials of the New Process Gear Company for providing the splendid facilities for such a successful meeting.

TORONTO CHAPTER

The Toronto Chapter of the Society held meetings on March 13 and 27. On the former date Professor O. W. Ellis continued his series of lectures on the Metallurgy of Iron and Steel.

The latter meeting was addressed by Chester B. Hamilton, of the Hamilton Gear and Machine Works of Toronto, who introduced the subject of Steels used in the manufacture of Gears. The address was informal in character and was followed by an animated discussion on numerous points raised by the speaker.

O. W. Ellis

TRI CITY CHAPTER

The April meeting of the Tri-City chapter, A. S. S. T., was held in the main dining room of the Davenport Chamber of Commerce.

This meeting was called to order by the chairman, Harold Brown, who stated that before he introduced the speaker of the evening, he wished to congratulate all members for their successful efforts in the membership drive that closed April 1st and netted fifteen new members.

J. V. Emmons, metallurgist of the Cleveland Twist Drill Co., spoke on the "Machinability of Steel," methods by which it is determined and controlled. Mr. Emmons told of the experience his company had had along this line for the past fifteen years.

He told of the experiments that had been made to determine the most suitable condition the steel should be in to produce the best machinability. He stated that it had been found that the steel in a certain condition that was best for turning was not so good for milling, and the condition that was best for milling was not so good for turning, so that they had to arrive at a medium that would be best for both.

He also stated that to determine this condition of the steel both the analysis test and the microscopic test had to be used as either one alone was not sufficient.

Mr. Emmons' talk was further illustrated by lantern slides, and proved to be very practical, and was well received by all. Much discussion ensued during these presentations and after the talk.

Among out of town members and friends present were five representatives of the Walworth Mfg. Co. of Kewanee, Ill., and four members of the faculty of the University of Iowa at Iowa City.

Mr. Emmons while in the Tri-Cities visited several Moline Plants in the morning with Mr. Bornstein and Davenport Plants with Mr. Scherer in the afternoon.

C. F. Scherer.

WASHINGTON CHAPTER

The February meeting of the Washington Chapter was addressed by Marcus A. Grossmann on the subject of "Manufacture of Some Special Alloy Steels." This was the third of a series of four meetings devoted to the alloying elements in steels.

At the first meeting Dr. B. D. Saklatwalla discussed the manufacture of the various ferro-alloys and their role in steel making. Consideration was given to the historical phases of the development of furnace equipment for the manufacture of ferro-alloys, the details of those several types now in use and upon which descriptions have been made public and the principles underlying the design of these furnaces. The effect upon the properties and the composition of the metallic product, of various designs and methods of operation was also described. The paper concluded with a description in a most illuminating manner of the general effects of the various commonly used alloying elements upon iron and its alloys with carbon.

The January meeting was addressed by Dr. Birger Egeberg on "Some

Structural Alloy Steels.'' Dr. Egeberg laid particular stress upon the processing, properties and applications of steels high in manganese giving explanations for the various peculiarities of alloys of this character and explaining the metallurgical and metallographic reasons for some of the apparent anomalies. He also devoted considerable time to the nickel steels, chromium-vanadium steels and chromium-nickel steels used in structural assemblies. His experience with highly alloyed chromium-nickel steels of the deep-hardening type which show great differences in temperature between the thermal critical points on heating and the reverse effects on cooling were particularly interesting; these steels permit of hardening from very low temperatures thus largely avoiding the dangers of cracking and warping of large or intricate sections, so often experienced when quenching from above the A_3 point.

Mr. Grossmann, on February 20th, discussed the special alloy steels of the harder grades taking up in succession ball steels, magnet steels, oil-hardening steels, hot work steels and the fast finishing steels. The discussion of ball steels was confined largely to the defects occurring in manufacture and the means for overcoming each. Distinction among the magnetic steels of various compositions was made largely upon the basis of the differences in their electrical characteristics. Some description was also given of the machinability after cold cutting and of the effects of hot working and reheating subsequent to rolling at the mill. In considering the oil hardening steels and the hot working steels, details of dimensional changes on hardening and tempering were described and a comparison drawn between the changes in these steels and those in high speed steels. The relation of these dimensional changes to the working temperature of the hot work steels and the methods to be employed in avoiding growth during use were also discussed. The effect of chromium in improving the quality and ease of manufacture of the fast finishing steels was explained as being due to the effect of this element upon the solubility of the complex tungsten-iron carbides in the solid solution matrix. This talk concluded with a discussion of the McQuaid-Ehn test, including speculation as to the cause of the observed effect and also the value of the test as an indication of general steel quality.

Extended discussion followed all of these three presentations, and, as is quite usual in the Washington Chapter, each ultimately degenerated into a many-sided exchange of views on the variables of the steel-making process and their effect upon those properties of steel usually associated with the term ''quality.''

The fourth meeting of the series to be held in March will be given over to High Speed Steel.

Jerome Strauss.

The following is a summary of the lecture entitled ''The Theory of High Speed Steel'' by Dr. Carl Benedicks, presented before a joint meeting of the Washington Academy of Sciences, Washington Society of Engineers, Chemical Society of Washington and Washington Chapter of the A. S. S. T.

The talk departed considerably from the title in that the subject matter was a consideration of the hardening of steels in general and dealt with the hardening of high speed steel to only a small extent.

According to Dr. Benedicks, metals may be hardened in three ways:

(1) By cold working
(2) By adding a hard constituent distributed in finely divided form throughout the metal
(3) By dissolving in it another metal and maintaining a homogeneous solid solution.

In considering the mechanism of hardening by cold working Dr. Benedicks explained the two types of plastic deformation of crystalline material, namely, the movement by translation of a portion of the crystalline unit and also by rotation of parts of a crystalline unit. In the latter case the orientation of the portion which rotated differed from the orientation before movement occurred. The former action resulted in the development of slip bands and the latter led to the formation of twinned crystals; both of these phenomena are familiar to metallographists.

In considering hardening by the second method the familiar example of the effect of cementite in annealed and spheroidized steels was referred to. Mention was also made of the analogy to the hardening of beeswax and other compounds of like consistency when intimately mixed with hard powdered mineral substances.

The hardening by solid solution was given more time and considered in greater detail than the other methods of hardening. Dr. Benedicks explained that the hardness of alloys of mutually soluble metals was such that there is always a range of compositions that would give higher hardness values than either of the constituent metals. Using composition as the abscissa and hardness as the ordinate it was explained that the slope of the hardness-composition curves would vary in accordance with the character of the metals forming the system and that the greater the degree of dissimilarity between the two metals the steeper would this curve become. The curve of electrical resistivity paralleled very closely the curve of hardness. Very similar phenomena were found in the study of solid solutions of many organic substances. Substances chemically identical but differing in their optical characteristics produced hardness curves showing practically no variation from 100 per cent of substance A to 100 per cent of substance B, whereas substances chemically different showed very great increases in hardness throughout the system.

Dr. Benedicks then considered the changes taking place in the iron-carbon system at the temperatures of the various transformations paying particular attention to the properties and crystalline forms of gamma and alpha iron and to the solubility of carbon in these two phases. He described austenite as a solid solution of carbon in gamma iron and martensite as a solid solution of carbon in alpha iron. He considered austenite to be soft because it is merely a supercooled and not necessarily even a saturated solution. On the other hand he considered martensite as hard because alpha iron cannot normally hold carbon in solution, and that in this constituent

the carbon is in forced solution; in other words, the solution is not only supercooled but also supersaturated.

Dr. Benedicks then considered changes in the thermal critical points, particularly the A_3 points, due to the addition of alloying elements to steel. He explained that those elements such as carbon, manganese and nickel which have the same crystalline form as gamma iron, tend to maintain the stability of their solutions in gamma iron and therefore lower the temperature at which the gamma iron is transformed to alpha iron. On the other hand such elements as chromium, tungsten and vanadium which have the same crystal form as alpha iron caused the opposite effect and increased the temperature at which A_3 occurs. Thus in high speed steels A_3 is very much higher than in carbon steels and the supercooled, supersaturated solution being at a temperature further from its transformation point requires higher heating in order to destroy the hardening effects of the quenching operation. Dr. Benedicks also referred to the discovery by X-ray methods of a carbide phase in high speed steel having a probable formula of Fe_6W_3C; he mentioned the possibility of the solid solutions of this compound in the alloyed ferrite having some bearing upon the properties of high speed steels. Dr. Benedicks did not consider it necessary to assume a fine grain size in the alpha iron of martensite to explain the hardness of this component. He states that the broad bands of X-ray spectrograms may be due not only to extremely fine grained iron but also to crystal lattice distortion resulting from great internal stress; which applies to the case of martensite is still undetermined.

In commenting upon the hardness of duralumin, Dr. Benedicks claimed to be not completely satisfied by existing theories, maintaining that the fact that the electrical resistivity changes closely paralleling the hardness changes was evidence of solid solution influences being at work. He also questioned whether existing theories of the hardening of certain aluminum-zinc alloys were correct. Even though no supporting evidence for the allotrophy of zinc had yet been forthcoming, the equilibrium diagram for the aluminum-zinc system in the vicinty of 30 per cent aluminum was very similar to that portion of the iron-carbon diagram which deals with the changes taking place in carbon steels.

Jerome Strauss.

WORCESTER CHAPTER

The March meeting of Worcester chapter was held on the evening of the 26th at the plant of the Worcester Gas Light Co. A chicken pie supper was served at 6:30 p. m. to the forty-one members and guests who attended, after which A. C. Frey, plant superintendent of the Worcester Gas Light Co., gave a talk on "Gas Manufacture." Mr. Frey described the two processes most generally in use; the coal gas process—and the process of making carburetted water gas. During his talk Mr. Frey asked for questions after completing the description of each step in the process and, judging by the number and variety of questions asked, the subject proved very interesting.

After Mr. Frey's talk the party divided into groups which were con-

ducted through the plant by manager E. H. Bauer, Mr. Frey and Mr. Grabb, assistant plant superintendent.

A meeting of Worcester Chapter was held April 16 at the University Club. A supper was served at 6:30 p. m. after which the members were addressed by L. Dwight Granger of the Wickwire-Spencer Steel Corp., a member of Worcester Chapter.

Mr. Granger's topic was "The Manufacture of Springs." He brought out that the spring manufacturer's problem was a very different one from that of the machine manufacturer in that machine design usually calls for rigidity while the design of a spring usually calls for it to sustain a definite load at a definite compression or extension.

The modulus of elasticity is an important factor in the design of springs. Mr. Granger stated that the volume of metal in springs made to do the same amount of work is always the same.

He divided his discussion into three main groups:

Round wire helical springs to be used under compression and torsion, motor springs, such as clock springs and motor springs and special springs made up of round or flat wire, the latter being hand tempered after they are formed.

An interesting point brought out in connection with helical springs was that springs of the same dimensions made of high or low carbon steel would support the same loads at the same deflection up to the elastic limit of the wire. In the case of high carbon steel however, the elastic limit would be higher thus giving the spring a greater maximum load carrying capacity.

Mr. Granger said that the old process of spring manufacture used acid open hearth steel; about 0.60 per cent carbon, manganese 0.35 per cent, silicon 0.10-0.20 per cent and sulphur and phosphorus below 0.05 per cent.

About 90 per cent of the springs now made are made of basic open hearth stock; carbon 0.55-0.65 per cent, manganese 0.90 to 1.00 per cent, silicon 0.15 to 0.25 per cent and sulphur and phosphorus below 0.05 per cent.

This material is very responsive to heat treatment and to satisfy the very exacting demands of manufacturers, only the best of furnaces, the best of material and the most careful heat treatment can be used.

About 50 per cent of the springs are made from oil tempered wire which is heat treated in a continuous process; the strands of wire being run through a long furnace to bring the temperature of the wire just beyond the critical point, quenching in oil and tempering in lead to between 750 and 800 degrees Fahr. The resulting material has a tensile strength of from 200,000 to 250,000 pounds per square inches and is capable of being wound around its own diameter.

The usual smallest commercial size of springs have a mean diameter of three times the diameter of the wire.

Springs made of oil tempered wire receive no final heat treatment after being wound and such a spring will perform, according to Mr. Granger fully as well as a chromium vanadium spring which does have a final heat treatment.

Mr. Granger stated that Swedish steel was considered best for music

wire and music wire springs and seemed to have some qualities superior to the best material manufactured in this country for that purpose.

Mr. Granger described the process of "patenting" which is used in the manufacture of all high carbon wires. After being drawn several times wire becomes brittle and hard necessitating a heat treatment to prepare it for further drawing. This process consists of heating to considerable over the critical point, and allowing the wire either to air cool or quenching it in lead at about 900 degrees Fahr. This restores the sorbitic structure of the wire leaving it with the highest tensile strength and greatest toughness.

In speaking of the application of springs to specific purposes Mr. Granger stated that the machine designer should have the spring designed to comply with the necessary load, compression or extension specifications before completing the design or building the machine in connection with which the spring was to be used. Often times this is not done with the result that it is practically impossible to make a spring which will fit into the design of the machine and still fulfill the required specifications.

In ordering springs the spring manufacturer should be supplied with all of the available information regarding what is required and, if possible, with a sample.

The question was asked as to how the pitch affects the strength of a spring? Mr. Granger answered this by stating that if two springs were made of the same length of the same diameter and the same size of wire, one having ten turns and the other five turns the one with five turns would support twice as much load at a given compression as the other.

The question was also asked as to how the load is figured on a clock or motor spring? Mr. Granger said that a very complicated formula had been worked out for this purpose but that considerable experimental work was often necessary. He cited a case where his company, was called upon to develop a spring for the Edison Diamond Disc Phonograph, where it was desired to play three 10 inch records without rewinding the spring; the ordinary spring motor being capable of playing only one ordinary record while the Edison 10 inch record due to the closer spacing of the grooves played twice as long and made twice as many revolutions as the ordinary machine. This, Mr. Granger said, was finally accomplished, but the spring case was 12 inches in diameter instead of 6 inches as before.

The meeting was a very live one, many questions being asked besides those noted. The attendance was only twenty-seven due to the date conflicting with the meeting of another association on the same evening but those who attended were amply repaid by Mr. Granger's interesting talk.

R. J. Phelon.

ADDRESSES OF NEW MEMBERS OF THE AMERICAN SOCIETY FOR STEEL TREATING

EXPLANATION OF ABBREVIATIONS. M represents Member; A represents Associate Member; S represents Sustaining Member; J represents Junior Member; and Sb represents Subscribing Member. The figure following the letter shows the month in which the membership became effective.

NEW MEMBERS

ABEY, H. R., (A-3), pyrometer salesman, Leeds and Northrup Co., 1271 Union Trust Bldg., Cleveland.

AXELSON MACHINE CO., (S-4), P. O. Box 337, Los Angeles.

ARMFIELD, C. E., (M-3), foreman carburizing, National Enameling and Stamping Co.; *mail* 2219 13th St., Granite City, Ill.

BETTRIDGE, J. C., (M-4), engineer of standards, Dodge Brothers; *mail* Box 666, Route 8, Detroit.

BLAKSLEE, R. C., (M-4), production supervisor, Rock Island Lines, Silvis, Ill.; *mail* 1718 14th Ave., Moline, Ill.

BOYD, B. S., (A-4), representative of Stanley P. Rockwell Co., Hartford; *mail* 14 Hartshorn Ave., Worcester, Mass.

BOYLE, C. L., (A-4), manager, Industrial Chemical Products Co.; *mail* 3200 East Woodbridge St., Detroit.

BREMMER, F. W., (M-4), metallurgist, Standard Seamless Tube Co., Ambridge, Pa.

BRESSEY, G. M., (M-4), laboratorian, Leeds and Northrup Co.; *mail* 6640 Ogontz Ave., Philadelphia.

BRUNN, FRANK, (M-4), metallurgical department, Dodge Bros.; *mail* 1139 West Hancock St., Detroit.

BUTLER, DWIGHT, (M-4), superintendent, Acme Steel Treating Co., Detroit.

BUTTERFIELD, IRVING, (M-4), metallurgical department, Cadillac Motor Car Co.; *mail* 3527 Howard St., Detroit.

CARLSON, C. A., (M-3), superintendent, Axelson Machine Co.; *mail* 3844 Walsh St., St. Louis, Mo.

CHRISTIAN, A. F., (Jr-4), student, University of Michigan; *mail* 1334 Volland St., Ann Arbor, Mich.

COUSINS, H. T., (M-4), chief chemist, Union Electric Steel Corp., Carnegie, Pa.

CRAFTS, WALTER, (Jr-4), student, Massachusetts Institute of Technology, Cambridge; *mail* 28, The Fenway, Boston.

CRESSMAN, H. E., (S-4), district manager, E. F. Houghton and Co.; *mail* Lumpkin and M. C. Ry., Detroit.

DAVIDSON, A. C., (M-4), executive manager, Dycast Steel Co., Collinsville, Conn.

DOLAN, S. T., (M-4), chemist, New Process Gear Corp.; *mail* 239 Cortland Ave., Syracuse, N. Y.

DUNCAN, J. A., (M-4), shop and equipment inspector, N. Y. Central Ry.; *mail* 1249 East 144th St., East Cleveland.

DWELLE, J. A., (A-2), Schuylkill Forge Co., 3rd and Luzerne, Philadelphia.

EAGLE, F. J., (M-4), special apprentice, American Steel Foundries, East Chicago, Ind.

EDELBURG, E. R., (Jr-4), drill press operator, Cleveland Twist Drill Co.; *mail* 1593 East 32nd St., Cleveland, Ohio.

EITEL, W. C., (M-4), inspector of airplanes and equipment, Air Service, Procurement Section, U. S. Government, 39 Whitehall St., New York City; *mail* 600 West 174th St., New York City.

ELKINS, G. W., (Jr-4), student, Massachusetts Institute of Technology, Cambridge; *mail* 19 Glengary Road, Winchester, Mass.

ERICKE, C. O., (A-4), salesman, Firth Sterling Steel Co., 710 West Lake St., Chicago.

FAIRCHILD, H. W., (M-4), hardener, General Electric Co., Lynn, Mass.; *mail* 70 Main St., Saugus, Mass.

FLETCHER, W. A., (M-4), distributor, E. F. Houghton and Co., 3527-29 King Ave., N. E., Cleveland.

FLOYD, ROBT. K., (S-4), general manager, Frank H. Floyd Co., 747 Beaubien St., Detroit.

FRAZER, W. R., (M-4), assistant metallurgist, Halcomb Steel Co., Syracuse, N. Y.

GARLINGER, M. T., (M-3), Pacific Telephone and Telegraph Co., Wells Fargo Bldg., San Francisco.

GILBERT, E. K., (M-2), draftsman, F. J. Ryan and Co., Philadelphia; *mail* 147 Euclid St., Woodbury, N. J.

GOODTZOFF, N. T., (M-8), chief of laboratory, Krasny Pootilowetz Works; also lecturer at Polytechnic Institute of Leningrad; *mail* Ulitza Stachek 67, Leningrad, Russia.

GRAY, H. E., (A-4), resident agent, Bethlehem Steel Co., Los Angeles, Calif.

HALL, A. S., (S-4), Thwing Instrument Co., 3339 Lancaster Ave., Philadelphia.

HAMBLEY, LESLIE, (M-4), steel temperer, Curtis and Company Manufacturing Co.; *mail* 5065-A Emerson Ave., St. Louis, Mo.

HARDING, JOHN, (M-3), metallurgist, Atlas Drop Forge Co.; *mail* 1926 Lyons Ave., Lansing, Mich.

HARDY, E. C., (M-4), general inspector, N. Y. Central Railway Company; *mail* Room 1414-466 Lexington Ave., New York City.

HAUSER, E. R., (M-4), metallurgist, National Tool Co., Madison and West 112th St., Cleveland.

HENRY, PETER, (M-4), pyrometer repair department, Ford Motor Co.; *mail* 1937 Scotten Ave., Detroit.

HOPKINS, R. Z., (M-4), plant superintendent, Hudson Motor Car Co.; *mail* 2576 Hurlbut Ave., Detroit.

HOYT, JOHN R., (M-3), Standard Steel and Bearings Co., Plainville, Conn.

HUNTER, F. M., (M-3), asistant superintendent, Verona Tool Works; *mail* 721 Third St., Oakmont, Pa.

KIRBY, F. W., (M-4), superintendent, Marseilles Works, Deere and Co., East Moline, Ill.

LANGE, W. J., (Jr-3), student University of Cincinnati; *mail* 1370 Ernst St., Cincinnati.

LEDL, G. H., (M-4), chemist, Park Drop Forge Co.; *mail* 13813 Orinoco Ave., East Cleveland, Ohio.

LEE, L. Y., (Jr-4), student, University of Missouri; *mail* Box 765, Rolla, Mo.

LELAURIN, HARRY, (M-4), Naval Gun Factory; *mail* 1435 Potomac Ave., S. E., Washington, D. C.

MCDILL, BROWN, (M-4), clerk, Crucible Steel Company of America; *mail* 73 Ithaca St., Elmhurst, Long Island City, N. Y.

MCILWAIN, M. V., (Jr-5), student, Missouri School of Mines, Rolla, Mo.; *mail* Okawville, Ill.

MELOCHE, D. H., (M-4), metallurgist, Holley Carburetor Co., Detroit.

MILLER, ROBT. K., (Jr-4), student, Missouri School of Mines, Box 420, Rolla, Mo.

MILLERS, W. E., (M-4), superintendent, International Gear Co., P. O. Box 36, Lakewood, Ohio.

MOBIUS, C. E., (M-4), engineer of materials and inspection, Western Union Telegraph Co., 195 Broadway, New York City.

OSTERHUS, R. C., (M-4), factory engineer, Atlas Ball Co.; *mail* 4258 North Darien St., Philadelphia.

PARKE, W. H., (M-4), 941 West 34th St., Los Angeles.

PENDLETON, M. B., (M-4), general manager, Plomb Tool Manufacturing Co.; *mail* 2209 Santa Fe Ave., Los Angeles.

REINHART, EMIL, (M-4), superintendent, Ford Motor Co.; *mail* 141 North Front St., Hamilton, Ohio.

RICE, H. C., (A-4), salesman, E. F. Houghton and Co.; *mail* 300 Potters Ave., Providence, R. I.

RIEGEL, G. C., (M-4), works manager, Gerlinger Electric Steel Castings Co.; 588 67th Ave., Milwaukee.

ROCK, L. A., (M-4), master mechanic, Lavine Gear Co.; *mail* 1175 25th Ave., Milwaukee.

ROQUET, L. L., (M-4), metallurgical department, Dodge Bros.; *mail* Room 528, Y. M. C. A., Detroit.

SCHEUER, HENRY, (M-4), vice president, secretary and superintendent, Worden Tool Co.; *mail* 1854 Scranton Road, Cleveland.

SIEB, C., JR., (M-4), plant engineer, Reo Motor Car Co.; *mail* 1001 West Hillsdale St., Lansing, Mich.

SPROUL, A. A., (Jr-4), Colorado School of Mines, Golden, Colo.

STEWART, A. H., (M-3), metallurgist, General Electric Co., River Works; *mail* 71 Lynnfield St., Lynn, Mass.

TAFT, F. S., (A-4), salesman, Houghton and Richards, Boston; *mail* 8 Myrtle St., Providence, R. I.

TAYLOR, H. N., (S-3), president, N. & G. Taylor Co., Philadelphia.

WALLS, B. D., (M-4), superintendent, L & I White Co.; *mail* 143 Perry St., Buffalo.

WARREN, E. C., (Jr-4), 21 Mallon Road, Boston 21, Mass.

WEIR, F. W., (M-3), mill superintendent, Spang Chalfont Co., Inc., Etna, Pa.

WEMPLE, H. F., (M-4), furnace engineer, Eclipse Fuel Engineering Co., Rockford, Ill.

EMPLOYMENT SERVICE BUREAU

The employment service bureau is for all members of the Society. If you wish a position, your want ad will be printed at a charge of 50c each insertion in two issues of the Transactions.

This service is also for employers, whether you are members of the Society or not. If you will notify this department of the position you have open, your ad will be published at 50c per insertion in two issues of the Transactions. Fee must accompany copy.

Important Notice

In addressing answers to advertisements on these pages, a stamped envelope containing your letter should be sent to AMERICAN SOCIETY FOR STEEL TREATING, 4600 Prospect Ave. Cleveland, O. It will be forwarded to the proper destination. It is necessary that letters should contain stamps for forwarding.

POSITIONS WANTED

TALLURGIST—Young man, well educated, with years experience in chemical and metallurgical k (control and research) in large steel plant res permanent situation where chance of ad- cement will be offered. Will gladly consider con- tion that would eventually lead to position of sales esentative. Details on request. Address 4-1.

RDENER FOREMAN with a thorough knowledge the heat treatment of high speed, carbon and r steels and carburizing, is open for engagement. held executive positions for the last 12 years. 38. Married. Address 5-5.

USTRIAL POSITION is desired by assistant pro- r of metallurgy and metallography in leading thern University. 33 years of age. Married. S. degree in chemistry with major work in metal- raphy. Experienced in microphotography and py- metry. Has theoretical training necessary for the ing of a good practical man. Always willing to k. Address 4-30.

PERINTENDENT of wire drawing desires posi- with opportunity for advancement. Six years' erience as superintendent of cold drawing plant, ling all grades and shapes of steel. Two years' erience in metallurgical laboratory and heat treat- department. Address 4-20.

ISTANT TO PRODUCTION MANAGER, SUPER- NDENT OR ENGINEER OF TESTS, desires tion. 38 years of age, 15 years' experience on uction and in laboratories of large steel plants, dries and auto manufacture. Graduate chemist, llurgist, metallographist and heat treater. Also alle University training in accountancy and cost unting. Address 4-25.

POSITIONS OPEN

SALES ENGINEER: Familiar with selling engineering specialties or instruments. Must have had several years' selling experience. Not over 35 years old. Interesting proposition for man with this experience. College graduate preferred, although not necessary. Location in east preferred. Address 5-10.

WANTED STEEL MILL CHEMIST experienced in the analysis of steels. Man to have charge of chemical laboratory and required to make routine analyses of steels. Also have charge of the weighing of burdens for electric steel furnaces. Applicant to be 25 to 30 years old. Cleveland district. Address 5-1.

WANTED young man for steel and non-ferrous analytical work with some knowledge of steel and its heat treatment. Buffalo and Rochester district. Address 4-5.

WANTED THOROUGHLY EXPERIENCED HARDENER FOREMAN—Must have executive experience and complete knowledge of the heat treatment of high speed, carbon, alloy steels and carbonizing. Hardening plant is constructed with all modern appliances. State age, experience and salary expected. Address 4-10.

WANTED RECENT GRADUATE IN METALLURGY for work in metallography under a specialist, in Eastern plant. If applicant is located in East, will arrange for personal interview. Address 4-15.

FOR SALE

FOR SALE: 50-Ton Tinius Olsen Belt Driven Testing Machine with full equipment for steel test bars. Practically new. Price very reasonable. Address Bay State Machinery Co., 54 Old Colony Ave., South Boston, Mass.

HEAT TREATING EQUIPMENT FOR SALE: Two No. 150 Bellevue Furnaces. Brand new. Never used. Low price for immediate sale. Address Curtiss Aeroplane & Motor Co., Inc., Buffalo, N. Y.

Items of Interest

THE Republic Flow Meters Company of Chicago have recently published a new pyrometer catalog entitled, "Republic Pyrometers," which describes in a very efficient manner the equipment and methods used in the manufacture of their product. Many illustrations are included.

Professor H. M. Boylston, professor of Metallurgy, Case School of Applied Science, Cleveland, has recently been re-elected as representative of the American Institute of Mining and Metallurgical Engineers to a second three-year term on the Board of Engineering Foundation, an institution of research, whose objects are: The furtherance of research in science and engineering, or the advancement in any other manner of the profession of engineering for the good of mankind.

A booklet has recently been published entitled, "New Pickelette Pickling," which covers improvements made in the use of "Pickelette," by the distributors and also includes the changes dues to the more modern method of handling material during treatment. Paul F. Hermann is manager of the Pickelette Department of the William W. Hearne, Inc., with offices in the Century Building, Pittsburgh. The main office of the company is in the Real Estate Trust Building, Philadelphia. Upon request, Mr. Hermann will be glad to confer with those considering the use of "Pickelette" and to supervise tests at their plants.

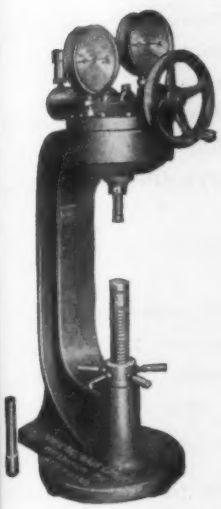
The Chemical Catalog Company, Inc., New York City, have recently published a new book entitled, "A Text Book of Metallography," by Gustav Tammann, director of the Institute for Physical Chemistry in Göttingen. This has been translated from the third German edition with the permission of the author, by Reginald Scott Dean and Leslie Gerald Swenson, metallurgical engineers, Western Electric Company, Inc.

The experiments in the field of metallography have increased with unequalled rapidity in the last ten years and there has been considerable work concerned particularly with practical questions. The field of this text-book can accordingly be designated as the theory of metal working.

The author has attempted to make the beginner as well as the more advanced student familiar with the characteristics, origin and properties of metals and their alloys.

This book is divided, corresponding to the chemical structure of the bodies treated, into one, two, three and multi-component systems. With the one component system the dominationg properties for crystallization, the linear crystallization velocity and the tendency to spontaneous crystallization are comprehensively treated.

S. M. Co. Brinell Machine



This machine applies a pressure of 3,000 Kilos to a 10 mm. ball and gives results in Brinell numerals, the international standard for indicating hardness of metals.

The Pressure is applied quickly and evenly, and a patented feature prevents the leakage of the hydraulic fluid.

Pieces from $\frac{3}{16}$ inch to 12 inches may be accommodated. The anvil is adjustable to irregular shaped pieces.

The Standard Machine Adopted by

American Can Co.
American Machine & Mfg. Co.
E. C. Atkins & Co.
Canadian Fairbanks Morse Co.
Carbon Steel Co.
Carnegie Steel Co.
Chicago Pneumatic Tool Co.
Columbia Steel & Shafting Co.
Curtiss Aeroplane & Motor Co.
Dayton Engineering Laboratories
Dominion Steel & Foundry Co., Ltd.
Eagle Pitcher Lead Co.
Firth-Sterling Steel Co.
Henry Ford & Son, Inc.
General Electric Co.
Hughes Tool Co.
Latrobe Electric Steel Co.
Lincoln Motor Co.
Maxwell Motor Co.
McMyler Interstate Co.
Nash Motors Co.
Oliver Chilled Plow Works
Parish & Pool Co.
Piston Ring Co.
Pittsburgh Testing Laboratory
Pollak Steel Co.
Premier Motor Corp.
Railway Steel Spring Co.
Standard Foundry Co.
Standard Steel Car Co.
Standard Steel Spring Co.
Studebaker Corp.
Underwriters' Laboratories
Union Switch & Signal Co.
Vanadium Alloys Steel Co.
Westinghouse Electric & Mfg. Co.

And Many Others

Send for descriptive bulletin 103

SCIENTIFIC MATERIALS COMPANY

"Everything for the Laboratory"

PITTSBURGH, PA.

Under the binary systems thermal analysis is treated by the description of typical ideal equilibrium diagrams and their corresponding surface of heat content, after which the intimate connection between thermal phenomena on crystallization and the structure of the aggregate is explained.

A summary of the author's knowledge of the relations of two metals closes the general part of the discussion of two component systems. This is followed by the equilibrium diagrams of only nine binary systems.

There follow two chapters on the physical and chemical properties of binary alloys, the second of which is based on the author's monograph, Die Chemischen und Galvanischen Eigenschaften von Mischkrystallreihen und ihre Atom Verteilungen (Leipzig, L. Voss, 1919.)

The elements and the crystallization of three component systems are reviewed so far as is necessary.

The conclusion is a chapter on the phase rule which upon mature consideration was introduced after the reader will have discovered the necessity for such a rule in the treatment of three component systems. The author has discussed metallography essentially on the basis of his own experiments.

The United States Civil Service Commission announces the following open competitive examination: for the position of Assistant Chemist (Metallurgy).

Receipt of applications for assistant chemist (metallurgy) will close June 15. The examination is to fill vacancies in the Ordnance Department, Navy Yard, Washington, D. C., at a salary of $6.40 a day.

The duties of the position consist of routine chemical analysis of steel, bronze and other ferrous and nonferrous alloys for foundry control and other technical purposes, and also of all raw materials required in the production of such alloys.

Full information and application blanks may be obtained from the Secretary of the Fourth United States Civil Service District, 1723 F Street, N. W., Washington, D. C.

H. A. Anderson, formerly chief engineer with the Mahr Manufacturing Co., Minneapolis, Minn., is now with the Johnstown Manufacturing Co., Minneapolis, Minn., in the capacity of chief engineer.

Alfred L. Lovejoy, age 59, died at his home in Greenwich, Conn., on April 6th after a short illness. Mr. Lovejoy was well known in the machinery trade after an association of many years with the Pratt & Whitney Company of Hartford.

The Firth-Sterling Steel Co., E. S. Jackman & Co., agents, has moved its Los Angeles, Cal., office from 336 East Third Street to larger quarters at 2154 Santa Fe Avenue. William Ely Nelson, who has been with the company almost 25 years, is Pacific Coast representative.

The University of Pittsburgh is broadcasting a series of radio education lectures on industrial developments from station KDKA, Pittsburgh.

A Valuable Service

It is our policy and practice to co-operate with our customers and prospects to such an extent that we can supply that particular grade or analysis of tool steel or alloy steel best suited to the particular purpose for which the steel is to be used. We are prepared to furnish not only the ordinary classes of high-grade steels made to our customer's specifications, but also to co-operate with them in the manufacture of new and special alloy steels.

We should like to make a thorough study of your requirements so that, with the special care that is exercised in the selection of raw materials and the constant attention that is given to workmanship, we can feel that we are supplying our customers with steel which will give the greatest service and efficiency in the products they produce. Our Metallurgical Department is at your service. You can call on our men to go to your factory or your men are welcome to come to the Simonds Steel Works with samples of your products to discuss the matter.

Our chemical, physical and metallurgical laboratories are most modern and complete.

Our research men are not only thoroughly trained in the theoretical science of high-grade steel making, but also experienced in the practice of the same.

SIMONDS SAW and STEEL CO.

Steel Mills, Lockport, N. Y.

BARS SHEETS BILLETS

Dr. Stephen A. Goodale, professor of metallurgy of the School of Mines of the university, recently talked on the opportunities for scientific research in the steel industry. A pamphlet containing seven of these brief addresses has been compiled by William A. Hamor, assistant director Mellon Institute of Industrial Research, University of Pittsburgh.

G. H. Clamer, past president of the American Foundrymen's Association, and a member of the board of directors, will deliver this year's exchange paper before the meeting of the Association Technique de Fonderie de France. It will be entitled "The Practice Followed in the United States in the Manufacture of Railroad, Car and Locomotive Bearings." Mr. Clamer can speak with authority on this and other non-ferrous subjects because he was the first chemist to be engaged regularly in the field of non-ferrous metallography in this country and has been engaged in research and production work with the Ajax Metal Co., Philadelphia, ever since he was graduated from the University of Pennsylvania in 1897. He was awarded the Elliott-Cresson gold medal, the highest award of the Franklin Institute, Philadelphia, because of his researches in foundry chemistry and metallography.

Clifton Taylor, who has been connected with the Molybdenum Corporation of America in various capacities, since its organization, has taken charge of sales and development, succeeding H. H. Davis, resigned.

The United States Civil Service Commission announces the following open competitive examination for the position of Chemical Engineer.

Receipt of applications for chemical engineer will close May 19. The examination is to fill a vacancy in the Fixed Nitrogen Research Laboratory, Department of Agriculture, Washington, D. C., and vacancies in positions requiring similar qualifications. The entrance salary is $3,800 a year. Advancement in pay may be made without change in assignment up to $5,000 a year.

Full information and application blanks may be obtained from the United States Civil Service Commission, Washington, D. C., or the secretary of the board of U. S. civil-service examiners at the post office or custom-house in any city.

M. K. Epstein has discontinued the business of the Heat Treating Equipment and Supply Company of Hartford, to accept the position of district manager for Gilbert & Barker Manufacturing Company, Springfield, Mass., at New York, with offices at 26 Broadway. Mr. Epstein represented the Gilbert & Barker Company in the Philadelphia district from September 1912 to March 1920.